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A TEXTBOOK

ON

# ELECTRIC LIGHTING AND RAILWAYS

INTERNATIONAL CORRESPONDENCE SCHOOLS
SCRANTON, PA.

2

OPERATION OF DYNAMOS AND MOTORS
DYNAMO-ELECTRIC MACHINERY
ALTERNATING CURRENTS
ELECTRIC TRANSMISSION

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# OPERATION OF DYNAMOS AND MOTORS.

## INSTALLATION.

**1. Location.**—The location of a large dynamo or motor is a matter generally determined by local surroundings; that is, the position of the dynamo depends on where its engine may be, and the disposition of the motor depends on what it is to drive and where it is located. Assuming, however, that the conditions are such that the selection of a site for the dynamo or motor is not hampered by other considerations than that the machine shall be put in a place best adapted to itself, the following points should be kept in mind: It should be kept in a clean, dry, cool place, out of reach of drippings from steam and water pipes, and protected from dropping of water due to the condensation that sometimes takes place on an iron roof. The machine should preferably be placed where there can be a draft of air across it from windows or doors on opposite sides, and in such cases, if it is located on the ground floor, there should be ample means for sprinkling the street in the vicinity to keep down the clouds of dust that are otherwise sure to be present in dry weather. This precaution will permit a free circulation of air when it is most needed—in the hot summer months.

The space surrounding the machine should be clean and free from all obstructions. Where the machine is controlled

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from a switchboard, a man should be able to go from one to the other without going through a belt or past a number of obstructions. Dust from the street is injurious to the commutator, bearings, and general insulation of electrical machines, but dust from a coal pile or any kind of grinding or turning machine is even more so; therefore, the engine and dynamo rooms should be protected from the dust incidental to coal handling, and no emery wheels, grinders, speed lathes, etc. should be allowed in the room. Where motors are installed in rolling mills, forge rooms, carbon works, or places where a great deal of power grinding or finishing is done, the motor should be of an enclosed type, its bearings should be protected, just as those of a grinder are, and the machine should be properly caged.

2. **Foundations.**—Every machine of 25 horsepower, or more, should be provided with a substantial foundation, and this foundation should, if possible, be independent of the floor and walls of the building in which it is installed, to avoid communicating to them the very disagreeable vibration incidental to the running of the machinery. Where there are several machines to be installed, the idea is best carried out by having the whole floor space subconcreted and capped with a layer of cement or a wood floor. Where a single machine is to be installed, it is sufficient to limit the foundation to a little more than its floor area. In any case, solid brickwork is the best foundation, but where its use is impracticable, a substantial wooden frame construction can be used. Even where the concrete or brick foundation is used, it is customary to cap this with a hardwood frame, served with a high-grade insulating compound of some sort; the layer of wood serves not only to insulate the metal frame of the machine from the ground, but it acts as a cushion to take up the blows and vibration. The insulation feature must not be defeated by having the bolts that secure the wood frame to the masonry come in contact with those that secure the metal frame of the machine to the wood.

No rule in regard to the depth of the foundation can be given to cover all cases, as the subsoil is so different in different places. In one section, bed rock will be found a few feet from the surface, while in another section of the country it will be necessary to drive piles to support the foundations for the heavier machines. Fig. 1 shows a style of foundation very much used; the foundation proper is made of brick laid with 1 part of the best cement to 2 parts of good, sharp sand. The surplus of excavation is filled in with a mixture of broken stone and cement, which is capped to a surface with pure cement. The masonry is built around the anchor bolts.

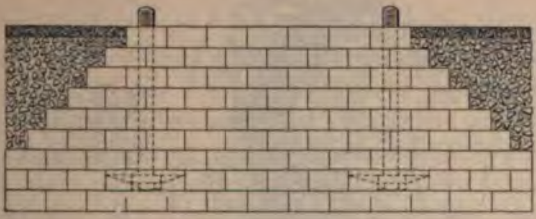

FIG. 1.

Wherever the machine is to be belt-driven, means should be provided for tightening or slacking the belt. On most machines this is usually accomplished by screws or by mounting the machine on rails or on a subbase and moving the machine by means of a ratchet lever and screw. As an example of this we may take the machine shown in Fig. 2. The foundation should in every case be so disposed that the distance between the driving and driven centers will allow one side of the belt to run looser than the other. This distance should be at least four times the diameter of the larger pulley.

**3. Erection.**—Small machines are, as a rule, shipped complete and ready to run, so that there is nothing to do but to put them in place, put the pulley on, and line them up. Large machines cannot be shipped with safety in an assembled condition, and some are so large that they could not be gotten through the door of a closed car; so they are dismounted and the parts marked and packed in separate parcels. It then falls upon the roadman or the purchaser to assemble them at their destination. This work should not be undertaken by one not familiar with such work, and even an expert should not be above consulting the blueprints and the marks on the parts.

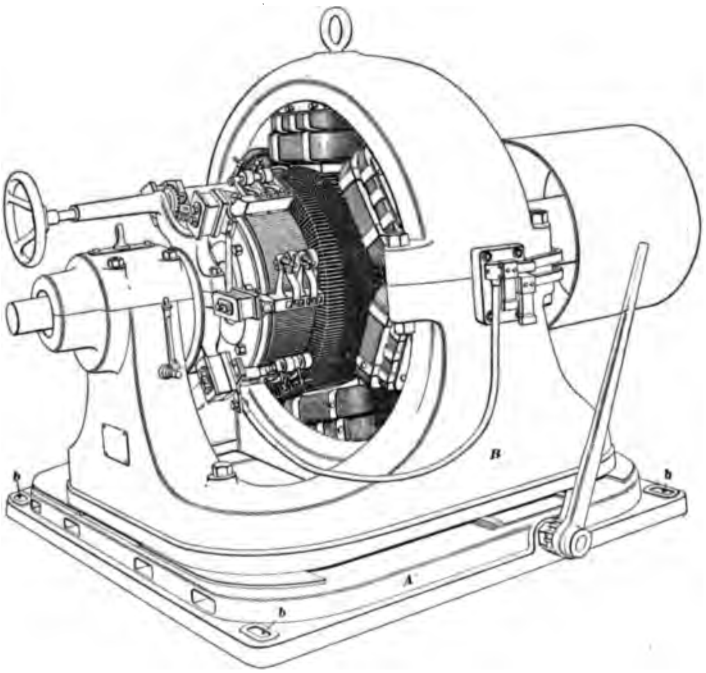

FIG. 2.

No man should try to assemble the parts of a heavy machine without being provided with the rigging devices adapted to the work. Large stations provided with large units are generally equipped with cranes to replace armatures or fields that may become burned out. Small stations are not so well fixed, so the installer must usually look them up for himself. As the construction of machines varies to some extent, so must the method of handling the parts. In order to be specific, the machine shown in Fig. 2 will be taken as the one to be assembled. This is a six-pole belt-driven street-railway generator of the Westinghouse type. The bedplate *A* and the lower half of the machine *B* are worked on to the foundation by means of crowbars and rollers; as the wooden sub-frame projects above the level of the floor, a false wood floor must sometimes be laid. The bedplate is then worked into such a position that the holes *b*, *b* in the four corners of the foot flange fall just over the bolts or bolt holes that they are intended to engage. The blocking is then taken out and the machine let down upon the foundation or frame, as the case may be.

**4.** The next step is to place in position and connect together the bottom field coils *c*, *c*; the field coils may be put in the top half of the frame at the same time, so that this part can be swung into position as soon as the armature is in place. Great care must be taken that the coils are slipped over the pole pieces with proper regard for the marked ends, or trouble will surely result. Field coils that do not weigh more than 200 pounds may be safely lifted into place, but great care must be taken not to bruise the insulation or bend or break the terminals. For handling heavier coils than this, and also for handling the armature and top half of the frame, tackle must be rigged immediately above the foundation. In rigging this tackle, the total height that the top half of the frame must be lifted to get it in place after the armature is in position must be considered. If a chain hoist must be used, do not attempt to lift a 4,000-pound armature or top field half with a 2,000-pound hoist—use a 4,000-pound hoist, or even two 2,000-pound hoists. To support the hoist, a rope is slung in several turns from a roof girder or from a crosspiece laid between two girders. Old cloth or carpet is interposed between the rope and the girder so that the former may run no chance of being cut. The hoist is hung at such a height as will enable its full hoisting range to be utilized. If in spite of all that can be done, the hoist does not have sufficient range for the highest lift, the lift will have to be divided into two stages. These two stages must be such that the end of the first lift leaves the part to be lifted as near to the floor as possible. The part is then securely blocked, the point of support of the hoist raised, and the lift completed. To put the armature in place, it is moved as close as possible to the machine, so that its tendency to swing in, due to its being out of the vertical line of the hoist, will be a minimum. This tendency must be further offset by means of a strain put on by a block and tackle or hand line applied at the side. The bearing parts of the armature shaft should be encased in cloth before lifting, to avoid nicks and dents. The pillow-blocks should be inspected to see that they contain no iron filings or other dirt, and should then be filled with a good quality of oil.

**5.** Under no circumstances should any of the weight of the armature be supported by any device in contact with the commutator; the point of support should always be the shaft. For handling small armatures whose pillow-blocks are removable, a couple of ordinary handle bars, such as those shown in Fig. 3, should be used, and for the heavier ones a rope sling *S* and spread bar *B* such as are shown in Fig. 4; note that the rope is crossed on itself when it passes through the hook. When handling a heavy armature, its commutator should be protected by a blanket or other padding to save it from knocks that may dent a bar or damage

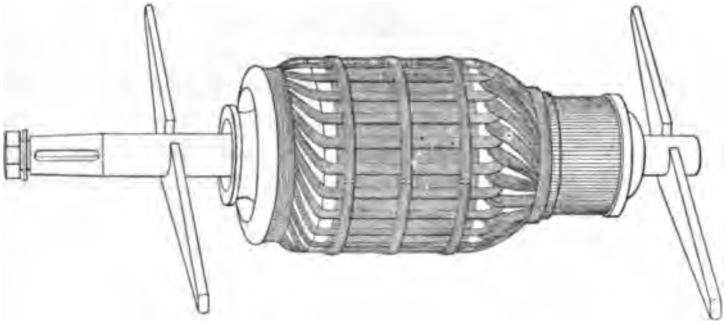

FIG. 3.

a band; the armature should not be rolled over the floor carelessly, as a nail head or a piece of hard matter of any kind in its path is liable to nick a band wire, so that as soon as the machine is up to speed and heated, causing some expansion, the band wire will break. As soon as the armature is swung over its final position, the shaft is wiped off with clean waste and served with a thin film of good cylinder oil. The bearings are then slipped on; in doing this, the oil rings must be lifted by running a clean round rod or stick in the end, otherwise the end of the shaft may jam one of the rings and bend or break it. Where spiral bearings are used, care must be taken to put them on the shaft as the marks call for, otherwise the oil will be fed out instead of in, and the box will run hot. All these points being looked after, the armature is dropped into place and given a few turns by hand to see that the oil rings work and that there is enough end play to prevent binding. Using the pulley end of the shaft as a straightedge, the machine is now leveled by means of a spirit level, split sheet-iron washers being put under the bedplate around the anchor bolts if one end must be raised.

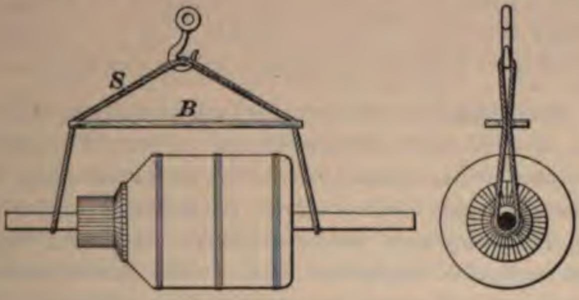

FIG. 4.

**6.** If the foundation and frame have been well made, little or no lining will be called for. With the armature in place, the top half of the frame, whose field coils have been previously connected, is lifted on. The joint between the top and bottom halves should be well cleaned before setting them together; it may be necessary to wipe off some white lead, put there to prevent rust, or to surface down a dent due to a falling tool. Where the machine has detachable pole pieces, the same care should be exercised in regard to the surfaces between them and their seats on the frame. When the top half is in place, the pulley is put on, the machine lined up to the engine that is to drive it or to the pulley that it is to drive, and the yoke, brush holders, and other fittings put on. The driving belt should have a cemented, not a laced, joint. It must be borne in mind that in order to make a good job of lining up the motor or dynamo, it is necessary that the device to which it is to be belted has been installed with the same care as the dynamo itself.

**7. Starting Up.**—If the machine is a dynamo, it is, of course, started up by means of its engine; if a motor, current from the line must be used. In either case, be sure that there are no tools or other parts lying on the belt or on the dynamo where they can shake off on to the armature or be sucked up by the fields. The machine should be run at about half speed for an hour or more to give bad bearings a chance to show their presence and to see that the oil rings do not stick. If all the parts of the machine seem to be in good working order, the speed can be run up to its normal rate, and the machine given a chance to pick up its field, but no load should be put on for several hours. Where the parts of a machine have been exposed and are damp, the insulation will be low, and arrangements should be made to bake the windings with current at low voltage, so that there may be no risk of a burn-out at the start; but in testing the insulation of a machine that is running on a grounded circuit, such as a street-railway circuit, unless the permanent ground is removed, the insulation will, of course, show a dead ground.

**8.** The machine should be turned over very slowly at first, so that in case it is not lined up exactly right the belt will not run off before the necessary change can be made; should the belt try to come off, it can, as a rule, be held on with a bar until the machine can be stopped; even if the belt does come off on the *outside* of the pulley, no special harm is done; but if it comes off *inside* of the pulley, it is liable to have one of its edges curled and stretched and it will give constant trouble afterwards. On this account, it is a good plan, if there is any doubt as to whether the pulleys are in line, to cant the machine pulley a little in favor of the outer edge.

**9.** In order for a dynamo to pick up its field, it is necessary that the fields have a little residual magnetism left over from the last charge. Electric machines, except some of the largest sizes, are always tested under load before they leave the factory, and, as a rule, retain enough of the magnetism to "pick up" on when they are installed. But sometimes on the way from the factory to their destination this magnetism is not only vibrated out of them, but in some cases the vibration has been known to reverse the polarity of the dynamos. Even machines in service a long time lose or reverse their residual magnetism for no apparent reason. In such cases, the fields must be recharged. In the case of an isolated machine, this recharging must be done from a battery, unless there is some other machine in the neighborhood that can be temporarily tapped to the outside line; where there is more than one machine, the field of the dead one can be charged from the live one; in such a case, the field leads must be either disconnected or the brushes lifted off the commutator of the dead one, to avoid running it as a motor. Of course, in the case of a motor, the field current is supplied from the line, so that with motors there is no trouble on account of the fields losing their magnetism.

## OPERATION.

**10. General Care of the Machinery.**—The dynamo or motor and all devices connected with its operation or regulation should be kept perfectly clean. No copper or carbon dust should be allowed to accumulate to cause breakdowns in insulation. The oil gauges and grooves should be kept in working order and the oil in the wells should be renewed at regular intervals. The brushes should be kept clean. They should be set and trimmed to fit the commutator, and copper brushes should be taken out once in a while, whenever they become clogged, and dipped in gasoline to cleanse them. When a machine is shut down, copper brushes should always be lifted just before the dynamo comes to a stop and they should not be let down until the machine, if a dynamo, is under headway again. New carbon brushes should be sandpapered to fit the commutator, by sliding a piece of sandpaper back and forth between them and the commutator. Do not use emery paper for cleaning the commutator, as emery is more or less of a conductor and may cause short-circuiting between the bars; also small pieces of emery become lodged in the brushes and scratch the commutator. The connections and all setscrews and bolts should be inspected regularly to see that none are liable to become loose and fall out. All screws that secure shunt-field or rheostat wires should be fixed by a drop of solder.

Oil should be used very sparingly, if at all, on the commutator; to lubricate it, put a film of vaseline on a canvas cloth, fold the cloth once, and let the commutator get only what goes through the pores. Never allow a loose article of any kind to lie on any part of a machine. . Oil cans should be made of brass so that they will not be attracted by the pole pieces. Do not allow a belt to run tight enough to cause a hot box, nor let it run so loose as to squeak and threaten to come off. When closing a switch, do not tap it in to see if everything is all right, but once the mind is made up that everything is as it should be, close the switch firmly. The operator's eyes and hands are of more importance and value than anything else in the station. If there is any doubt about whether a switch should be closed or not, do not close it until all doubt is removed. All switches should be left open when the machine is not in action. Circuit-breakers should be tried at frequent intervals to see that they are not stuck or set for the wrong load.

### BRUSHES.

**11.** On direct-current machines, the brushes and commutator require, perhaps, more attention than all the other parts of the machine put together. Brushes should in the first place be of sufficient size to carry the full-load current of the machine without heating. Brushes are of two kinds: *radial* and *tangential;* **radial brushes** point straight at the center of the circle that represents the outline of the commutator; their direction is parallel to the radius, as shown in Fig. 5 (*a*). **Tangential brushes**, Fig. 5 (*b*), are generally made of copper and are found, as a rule, on lighting machines. Radial brushes are made of carbon and are mostly found on power machines, though they are now largely used on lighting machines as well. Carbon brushes are used on machines whose output is at a comparatively high voltage, and, hence, low current; copper brushes, on machines of high current and low voltage. Also, carbon radial brushes are used on machines that must admit of being reversed in rotation. Carbon brushes are generally found on machines subjected to sudden and violent variations of load, while copper brushes are better adapted to conditions of slowly varying or constant load. Carbon brushes are usually copper plated to within $\frac{1}{4}$ inch or $\frac{1}{2}$ inch of their bearing ends, in order to give them better contact with the brush holders. Also, carbon brushes often contain a lubricant in the form of the paraffin with which the carbon dust is treated in the course of its manufacture, so that these brushes being self-lubricating, no compound or grease is needed on the commutator itself. With carbon brushes, the commutator takes on a dark-chocolate polish and the brushes emit a squeaking noise at starting or stopping.

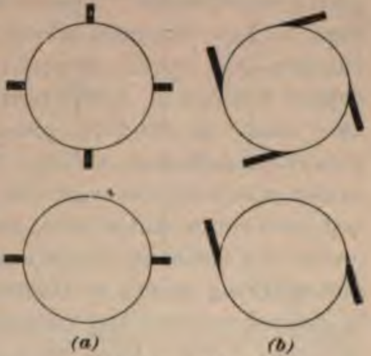

FIG. 5.

**12.** Carbon brushes are made in several grades of hardness, adapted to different conditions of working and different kinds of commutators. In stationary, direct-current work, soft carbon is used; on street-car work, hard carbon. Carbon has the great advantage that, being of relatively high resistance, it limits the value of the current generated in the coils that are short-circuited as they pass under the brushes and thereby reduces the sparking. By reason of this fact, carbon brushes admit of a wide variation in the load and hence in their non-sparking positions, without giving any trouble. This is why carbon brushes are used on high-voltage dynamos where there are sudden and violent changes that cannot be met by shifting the brushes. With copper brushes it is different; copper is of such low resistance that the short-circuited coil passing under a brush generates sufficient voltage to force a large current that causes sparking through the local circuit comprising the coil, two commutator bars, and the brush. This condition occurs if a variation in the load leaves the brushes out of the non-sparking points, so that copper brushes must, as a rule, be shifted to meet any variations in the load. Many kinds of copper brushes have been devised to meet this objection; in every case the object has been to increase the resistance in the path of the short-circuited coil without increasing the resistance to be traversed by the main current of the machine. To this end, brushes have been made of alternate layers of copper and of carbon, or have been made of copper wires or gauze.

In Fig. 6, *A* is the ring armature of a dynamo sending a current through lamps *L* by way of brushes *a*+, *a*–; coils *c*, *c* are passing under the brushes and are, therefore, being short-circuited by them through the local loops, *1–2–3–4–5–6–7*. It is not hard to see that if the center of the brush throughout its width be made of an insulating material, as indicated by the dotted lines, the local current due to the short-circuited coil cannot get from the heel of the brush to the toe, or *vice versa*, without first flowing up and down the full length of the brush, so that the short-circuited coil cannot generate so large a current, although the flow of the current in the main circuit of armature and lamps is not interrupted. On account of its decreasing the capacity of the brush, and for other reasons, it is not desirable to break the short local circuit, but a compromise is made by constructing the brush of alternate layers of copper and carbon or some metal whose specific resistance is high enough to reduce the current in the short-circuited coil, but not high enough to offer any serious impediment to the flow of the main current. Copper brushes are never made solid; they are made flexible, in one way or another, so that they may more readily conform to the surface of the commutator and bear at as many points as possible.

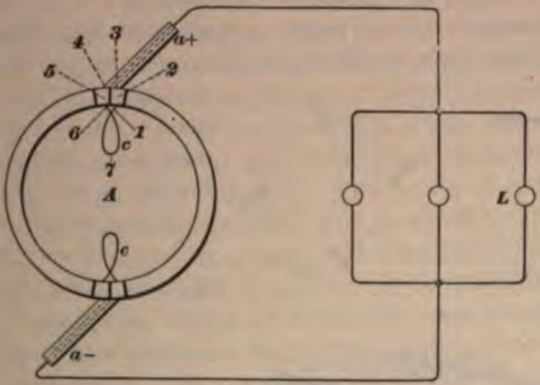

FIG. 6.

**13.** Ordinary copper brushes are not strictly tangential, this type being used only on small machines and on arc-light machines where the current is small. A form of strictly tangential brush is shown in Fig. 7 (*a*). Carbon brushes are often made as a kind of compromise between the tangential and the radial types, as shown in Fig. 7 (*b*). Just as in the case of the most common form of copper brush, it is neither exactly perpendicular nor parallel to a radius of the circle representing the end view of the commutator. No matter what style of brush is used, it should bear against the commutator with the proper tension. All generator brushes and stationary-motor brushes are so arranged that the tension can be regulated. Portable motors (street-railway motors) are not so fortunate. They are so limited in point of space and accessibility that the brush-holding device must be designed to average the right tension throughout the life of the brush.

The tension that a brush spring must have depends on the material and condition of the commutator and on the material of the brush itself. A copper brush does not, as a rule, call for as much tension as a carbon brush, and soft carbon will run with less tension than hard carbon; a rough commutator needs more brush tension than a smooth one; for given brush contact, large currents call for more pressure than small ones. Finally, where there are several brushes in each holder, the tension must be the same on all, so that they will all take about the same current. This tension should be great enough to pass the current without sparking or heating, but it should not be great enough to wear out the commutator unnecessarily. One of the features most conducive to success with brushes is the proper setting of them; this subject will be taken up in the article on "Sparking."

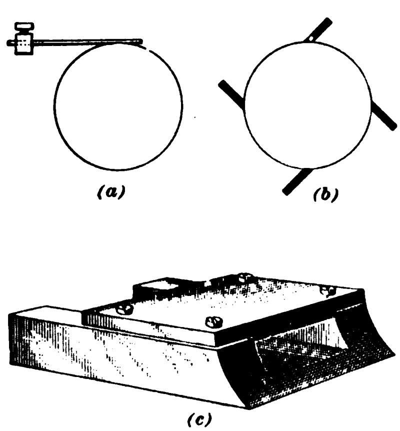

FIG. 7.

If the contact between the brush and the commutator is loose, the contact resistance will be high and heating will result. On the other hand, increasing the pressure beyond a certain amount results in very little reduction of resistance, but greatly increases the friction. For stationary work, a pressure of 2 to 2½ pounds per square inch of brush contact surface should be sufficient. For railway work, the pressure has to be much heavier on account of the jarring to which the motor is subjected.

**14.** One of the greatest weaknesses of carbon brushes is that they, at times, stick in the holder so that the tension spring is not strong enough to force down the brush to its place, and even if it does force it down, the pressure on the commutator will be too light. This very serious fault may be due to either of two causes: lack of uniformity in the thickness of the brush or an excess of paraffin in the brush. If a brush is thicker at one end than it is at the other, it may go into the holder freely if put in thin end first, and might not go in at all on the thick end. The result of this is that as soon as the brush wears down to a point where the thick end enters the holder it sticks. On the other hand, the fault may be due to a nick or burr in the brush holder itself. The only way to get rid of all chance of such trouble is to have a hard-steel gauge for the brushes and another for the holders; discard all brushes that will not pass through the brush gauge freely and file out any holder that will not take the holder plug gauge. As a final check against a bad brush getting into use, always try the brush in the holder end for end. The common practice of sandpapering a brush to get it in is a very bad one, as it not only makes the brush lopsided, thereby impairing its contact with the main surface in the holder, but it also takes off the copper plating.

The second source of trouble—an excess of paraffin in the brush—is accounted for as follows: If a carbon brush is snugly fitted into the holder so that it slides back and forth freely, but without any clearance, while the holder and brush are cold, as soon as they become warm the paraffin oozes out, forms a paste with whatever carbon or copper dust there may be present, and causes the brush to stick. It is a very common occurrence to see brushes that have been giving trouble coated with a tough skin of carbon dust and paraffin that can be readily scraped off with a knife. It is very essential that the brushes should be kept clean and trimmed to fit the commutator; to trim them, an iron jig similar to that shown in Fig. 7 (*c*) should be used so that the bevel may be kept perfectly true. This jig is intended more particularly for filing copper brushes. Carbon brushes can be sandpapered to shape in place.

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### THE COMMUTATOR.

**15.** The **commutator** is the most sensitive part of a machine and its faults are liable to develop more quickly than those of any other part. When a commutator is in the best possible condition, it becomes a dark-chocolate color, is smooth, or glazed, to the touch, and causes the brushes, if of carbon, to emit a characteristic, squeaky noise when the machine is turning slowly. Under no circumstances should any weight be allowed to rest upon the commutator, nor should it be caught with a sling when the armature is being lifted. The commutator should preferably be set upon a tapered seat on the shaft, forced up to its seat, and secured with a nut and lock, besides being provided with a key to prevent turning. With such an arrangement, the problem of putting on or taking off a commutator is very much simplified. Great care should be taken to eliminate every possibility of the device becoming loose, as such a defect gives rise to others, among which can be named open-circuited leads and consequent sparking. Great care should be taken to secure the best insulation between the bars and the shell, and from bar to bar, as a breakdown in the commutator insulation has the same effect as a breakdown in the insulation of the armature winding itself. The commutator bars should be perpendicular to a plane at right angles to the shaft, so that the brushes will not, in effect, set on a diagonal and cover more bars than they should. To secure the best results, the brush holders should be set as close to the commutator as possible, so as to do away with chattering. This is most desirable on machines that are to run in both directions, and the brush holder should, on such machines, be designed to slide radially inwards, so that wear in the commutator can always be readily compensated for.

**16.** If a dynamo or motor is not abused with too much overload, if the brushes are set properly, and if the commutator is made of the proper material, it should seldom get rough. As a rule, sandpaper and emery cloth are used around machines much more than they should be. For ordinary roughness of the commutator, due to some temporary abnormal condition, it is well enough to use sandpaper, but for chronic roughness some more permanent cure must be applied, as there is some serious cause behind the trouble. Take any of the following troubles, for example:

If a commutator, when it is built, is not properly baked or screwed down after it is baked, it is liable to bulge out in the course of time under the action of the heat due to its normal load and the centrifugal force, or it may develop loose bars. In the case of the bulging of one side, sandpaper will not do any good, because from the nature of the way in which it must be applied, the low part gets as much sandpapering as the high part and the relation between the two is kept the same. The best thing to do with a commutator that bulges badly is to take it off, bake it so as to loosen the insulation, tighten it up well, and turn it off in the lathe. For ordinary curvatures of surface, that is, unevenness due to wear, it is customary to set up a tool post and slide rest on the bedplate of the machine itself and turn off the commutator in position.

If the machine is a dynamo, it is run from its engine, which must be run very slowly; if the machine is a motor, its speed must be cut down by putting a water resistance in series with the armature but not with the field; in either case, a tool with a diamond-shape point must be used and the speed must be such that the bars will not be burred nor the nose of the tool burned. Keep the cutting point just about opposite (but a trifle above rather than below) the center of the commutator. After the commutator is turned, it should be smoothed off with a file and sandpaper, any burrs between the bars should be picked out, and vaseline sparingly applied through the pores of a coarse canvas rag. Always have the brushes raised when sandpapering a commutator, even if the machine has to be given a start and allowed to run on its own momentum, because, otherwise, the brushes will catch all the dust, with the result that they are apt to get clogged or the commutator become scratched. Outside of this, it is dangerous to sandpaper a machine that runs with an excited field and at a high speed, because the flying copper dust might be the cause of a short circuit that will burn the operator. This has happened more than once.

A narrow scratch or several of them all around the commutator means that there are particles of hard foreign matter under one or more of the brushes; the best thing to do is to take out the brushes and clean them. A broad scratch around the bearing surface of the commutator probably means that one of the brush holders has been set too close or has become loose and slipped down to a point where it touches the bars. The same scratchy appearance around the ears of the bars probably means that the armature has too much end play or that one of the brush holders is set over too far.

**17. High Bars.**—A metallic click emitted twice, four times, or six times (according to the number of brush holders in use) per revolution, indicates a high bar in the commutator; in such a case, the brushes will be seen to jump a little when the high bar passes under them. A high bar can come about in either of two ways: it may be due either to a loose bar working out or to the fact that one bar is much harder than any of its neighbors, and, therefore, does not wear down at the same rate. If the high bar seems to be firm under a blow from a hammer, it will be safe to take it down with a file while the armature stands still; but if the hammer test proves the bar to be floating, it is a serious matter, and nothing short of a regular repair job will give satisfaction. In testing a bar or bars with the hammer, care must be taken not to nick or dent the commutator, as such a defacement will cause the high-bar click to be emitted and it will be misleading.

**18. Low Bars.**—A fault very much akin to a high bar but much more serious in most cases, is the low bar, which gives forth very much the same sound, but the brushes drop, instead of rising, as the fault passes under them. The low-bar trouble may be due to any of several causes: it may be due to the commutator having received a severe blow in the course of handling; to one or more bars being of poorer material than the rest; or it may be due to the gradual eating away of the bar on account of sparking at that particular place. On any but ordinary bipolar machines, a loose connection will generally affect more than one bar. The main difference between a high bar and a low one is in the amount of work required to remedy them. A high bar can be removed by filing down or turning down that bar alone to the level of the others, but to get rid of a low bar, the rest of the commutator must be brought down to its level. This means that unless the low bar or flat is very slight, the commutator must be turned off. There are several other faults pertaining to commutators that will be taken up under the head of "Sparking."

**19.** Of course the most serious condition is to have a commutator that is poorly made and of poor stock. If the mica and copper used are not of the proper relative hardness, one will wear down faster than the other, leaving the surface of the commutator a succession of ribs. If the mica is too soft, it will pit out between the bars, leaving a trough to fill up with carbon dust and in a degree short-circuit the

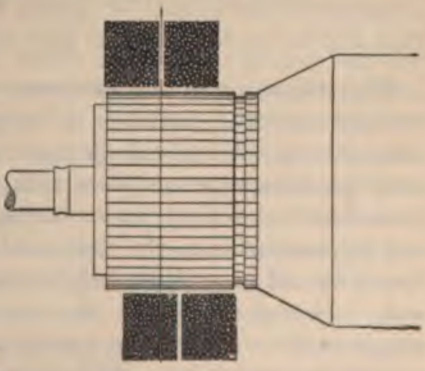

FIG. 8.

neighboring armature coils. If the mica bodies are too hard or too thick, the bars will wear in ruts and call for frequent turning down. The best combination for all-round work is made of soft, clear mica and hard-drawn copper. One practice of the day, and one that tends to materially increase the life of a commutator, is to so design the shape of the commutator bars and the set of the brushes, and to so proportion the end play of the armature that the brushes will play over the whole wearing surface of the commutator.

Fig. 8 shows such a disposal of the brushes, which are said to be **staggered.** The plan is to have the brushes so disposed that no ridges can be formed either on the outside edges or center of the commutator.

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### THE ARMATURE.

**20. Armatures** should be handled with great care, as it is an easy matter to bruise a coil or a lead, and this may not be noticed until the machine is started up and the trouble begins. All armatures should be supported by their shafts as much as possible, and should not be rolled around on the floor at the risk of having a coil punctured or a lead broken. When lying on the floor, they should lie upon padding of some sort. Extra armatures not in use should be kept housed in a dry place. The bearings and end play of the armature in use should be closely watched so that the core may not be let down on the pole pieces.

**21. Heating of Armatures.**—An armature should run without excessive heating; if it heats so as to give off an odor, any of several things may be the matter with it. It may be damp—a condition that, as a rule, is shown by steaming, but which can be better determined by measuring the insulation to the shaft with a voltmeter. This insulation should be at least 500,000 ohms when the machine is hot. If less than this, the armature should be baked, either in an oven or by means of a current passed through it in series with a lamp bank or water resistance. In using a water rheostat watch it closely, for the current increases as the water becomes hot. The baking current should not exceed the full-load current of the machine. In applying the current to the armature, be sure that the series field, if the machine has one, is not included in the circuit, and that the shunt field is broken; for if either field is on, the machine may start up as a motor. A machine that is too damp to run will heat at no load as well as at full load.

**22.** Another cause of heating under no load is due to the commutator being partially short-circuited all around from bar to bar, so that even when the coils are in the most active part of the field, a strong current can be set up through the local circuit provided by the coils themselves, the commutator bars to which their ends are attached, and the defective insulation between these bars. Such a condition often arises on an old machine, where the oil applied to the commutator has soaked into the mica bodies and carbonized. There is a case on record where the commutator was so short-circuited in this way that the machine would not start as a motor, because the applied current passed through the commutator instead of through the armature coils. The only true remedy for such a trouble is to put on a good commutator. Temporary relief can sometimes be obtained by taking a deep cut off the commutator, thereby removing the most defective part of the insulation.

**23.** If instead of the whole armature running hot, the heat is confined to one or two coils, the indications are that there is a short circuit either in a coil or between the two commutator bars that the ends of the coil connect. Such a short-circuited coil run in a fully excited field will soon burn itself out. A short circuit of this kind can be readily detected by holding an iron nail or a pocket knife up to the head of the armature while it is running in a field; any existing short circuits in the coils or commutator will cause the piece of metal to vibrate very perceptibly. One or more coil connections reversed on one side of the armature will, on a dynamo, cause a local current to flow from the strong half to the weaker half, and thereby cause all the coils to heat more than they should, besides decreasing the effective E. M. F. of the machine. On a motor, the effect is to decrease its counter E. M. F. so that it will take more current under given conditions, while the side containing the reversed coils will be hotter than the other side. The test for such a condition is to pass a current into the coils, one at a time, through the commutator bars, and to hold a compass needle over the coil that is connected to the two bars being fed; as soon as the reversed coils are reached, the compass needle will reverse the direction of its deflection. The coils must be disconnected and their ends reversed.

**24.** A broken armature lead or an open-circuited coil soon declares itself by causing a spark to travel around the commutator. A grinding, rumbling noise accompanied by excessive sparking and perhaps some slipping of the belt indicate that the bearings have worn down, letting the armature rub on the pole pieces. This is a trouble that takes place too often, and there is no excuse for it, for even if one does not know how long a set of bearings should run, he can easily tell how much wear has taken place by gauging the distances between the armature core and the top and bottom pole pieces. In such a case, the whole surface of the armature becomes hot and the bottom pole pieces and armature core show signs of abrasion.

**25.** An armature will sometimes get very warm through no fault of its own, but through heating from an abnormally hot bearing. Heat due to such a cause can generally be detected by the odor given off by the hot oil. Another serious trouble to which armatures are liable, especially motor armatures, is a bent shaft; this causes a very characteristic rattling noise to be emitted, the brushes spark, and the belt sometimes wabbles. The only thing to do with a bent shaft is to take out the armature and straighten its shaft. After straightening the shaft it may be necessary to turn down the commutator before it will run true, as the bend in the shaft may have existed to a slight extent for several months.

**26.** One very peculiar fault to which armatures are liable is known as a **flying cross.** This is due to a loose wire that only gives trouble when the armature is in motion. The loose wire may either be broken, it may have a loose connection, or it may have defective insulation that allows it to come into contact with other wires as soon as the armature comes up to speed. In any case, the fault gives no trouble as long as the armature is at rest, but as soon as it gets up to speed, the centrifugal force throws the loose wire out of place and causes the brushes to flash. If not located and removed, the fault will, in time, burn a hole in the armature insulation.

**27. Overloaded Armatures.**—One of the most common causes of general trouble and heating in an armature is overload; this may be due to ignorance or neglect or to an error in the instrument that measures the load. There is a great tendency on the part of owners to gradually increase the load on a machine until it may be doing about twice the work it is intended to do. If the machine is a dynamo, lamps are added to its load one or two at a time; in this way it is an easy matter to overload a dynamo without intending to. If the machine is a motor, small devices may be put on it, one at a time, until an overload is the result. Another very common way of overloading a machine is to increase the voltage at which it is run. Many operators have the idea that as long as the current through the armature does not exceed its proper value, it does not matter what the voltage is, as long as it is not high enough to break down the insulation. The load on a machine is given by the product of the current and the voltage, hence the voltage has a direct influence on the load. If the voltage on a machine is doubled and the current is kept the same, the load on the machine is doubled. Therefore, in order to keep the maximum load the same on a machine whose voltage has been raised, say 25 per cent., the maximum allowable current should be lowered 25 per cent. If the machine is rated at 100 volts and 50 amperes, and it is decided to run it at 125 volts, the current, to give the same load as before, should be 40 amperes. Where machines are running together in multiple, one may be taking more than its share of the load, due to poor equalization. Ammeters sometimes get out of order, read incorrectly, or stick; the needle may stay in one place while the load makes a change of 25 per cent., and the machine tender will be none the wiser.

**28.** When a dynamo is overloaded the commutator becomes rough, the brushes burn up and spark, the belt squeaks, and the machine grows hot all over. If it is possible to find a non-sparking point for the brushes at some intermediate load and at no load, this should also be possible at full load. If it is not possible, the symptoms point to overload and the ammeter should be tested. Of course, some machines spark badly no matter whether they are overloaded or not. This is specially true of the older types. When a machine persists in sparking when the commutator and everything else about it is in good condition, the trouble may generally be attributed to poor design. Some machines are so poorly designed that it is practically impossible to keep them from sparking.

## FIELD COILS.

**29.** We generally have two kinds of **field coils** to deal with, namely, *shunt* and *series*, or both, depending on the style of machine. These may be further subdivided into two classes, form-wound and shell-wound. Fine-wire fields are usually called **shunt fields** because they form a shunt or bypath for the armature current on a dynamo or the line current on a motor; they are of high resistance, so that they will take but a small part of the current supplied to or by a machine, and they are subjected to the full line voltage, as indicated in Fig. 9 (*a*), where *A* is the armature and *f* is the shunt field. Coarse-wire fields are usually called **series fields,** because they are in series with the armature, and should be able to carry the current that flows through the armature. They are of low resistance so that they may consume as little as possible of the voltage supplied to or by the machine, and as a result are subjected to but a small E. M. F., as indicated in Fig. 9 (*b*), where the drop through the series coils is supposed to be 2 volts. No matter what kind of field may have to be handled, the coils, leads, and connecting lugs should be handled with great care. The bearing surfaces of the coil should be brushed off before the coil is put in place, to avoid having any chips of foreign matter mashed into the insulation when the field bolts are screwed home.

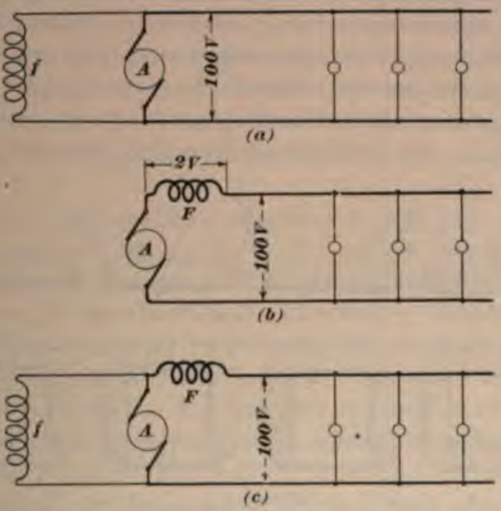

FIG. 9.

**30.** Field coils should be installed in such a way that when the current passes through them, if one pole piece is called north, the poles on both sides of it will be south. Coils, as a rule, are marked so that the workman may know exactly where they are to go and which end is to point toward the commutator. It is usually easy to tell by the shape of the field which face of it is to go next to the frame of the machine and which next to the armature. If the coils are not marked or if there is any doubt about the marks, the matter can be settled as follows: Set the field coils on the floor and line them up on edge, as shown in Fig. 10; connect them together and send a current through them. Get them, by trial, so that a piece of soft iron, held in the hand, will pass in an easy curve, as shown at *I*, from one coil to the other, the same end on. Should the piece of iron try to take the position shown at *I'* between any two coils, reverse one of them. When the coils are all turned so that the iron takes the curved path from one to the other, put them in place on the machine in this same relation, for then it is certain that they will alternate in polarity. A more certain test, perhaps, is to put the field coils into the machine as it is thought they should go (leaving out the armature), and test them with a compass or piece of soft iron the same as before. In using a compass, care must be taken that it does not stick, for then the lines of force of the field are liable to thread through it backwards and reverse its polarity; if this takes place just at the wrong time, it may be misleading. The reason for making the test without the armature in place is that the pole induced in the armature core opposite each pole piece is apt to influence the action of the compass.

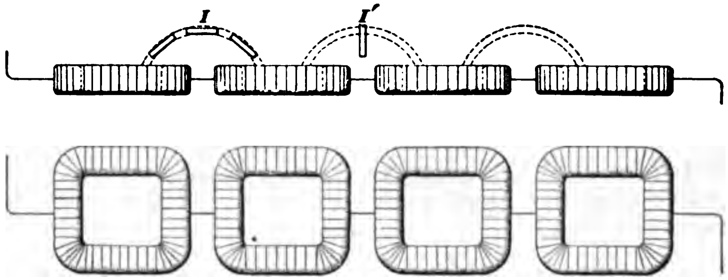

FIG. 10.

**31.** The effect of putting a field coil in end for end on a dynamo is to decrease the voltage that it will generate even on open circuit, and perhaps render the machine unable to generate at all. On a motor, the effect is to greatly increase the current required to start, to abnormally increase the speed after it is started, and to cause the brushes to spark. If a motor has only two fields and one of them is connected incorrectly, the machine will either not start at all or else it will start very slowly and take a very large current. A two-field dynamo cannot generate, under the same conditions even if excited from some other source, unless one coil happens to be a little stronger than the other, in which case the machine might generate a small E. M. F.

**32.** Where the machine is compound-wound, the two windings generally occupy parts of the same spool. Great care should be taken to get both sections properly connected. On a dynamo, if the shunt field as a whole is connected correctly but the series field incorrectly, the machine will pick up its field and hold it, but it cannot be made to take a full load; for as soon as the main switch is closed and current goes through the reversed series coils, their magnetizing force partially neutralizes that of the shunt coil, reducing the E. M. F. of the dynamo and fixing a limit above which the load cannot be made go. If the shunt fields are wrongly connected and the series field are correctly connected, the machine will not pick up its field at all on open circuit, and whether it will or not on closed circuit depends on the resistance of that circuit. This resistance must be very low for the comparatively few turns of series field to pick up through it, and even if it did, the resulting voltage applied to the terminals of the wrongly connected shunt field would bring about a neutralization of magnetism, and the E. M. F. would fall again.

**33.** On a motor it does not matter so much whether or not the shunt and series fields, as a whole, are connected to assist or oppose each other, unless the machine has been heavily over-compounded to run as a generator, in which case, if it is desired to use the series coils for maintaining constant speed under a variable load, it will be necessary to put a shunt in multiple with them. When a compound-wound motor is so connected that its series and shunt coils assist each other, it is said to be *accumulatively* connected, and it then has its greatest starting power for a given current. When the two fields oppose each other, the motor is said to be *differentially* connected, and if the strength of the two windings is in the proper relation, the speed of the motor will be constant within reasonable variations of load, if the voltage is constant. If, however, the series coils are too strong, the machine will run faster at full load than at no load, taking a great deal more current than it would with the reverse connection of the fields and perhaps sparking at the brushes.

**34.** Every dynamo, whether series-shunt or compound-wound, must have its fields connected in a certain way, in relation to the armature and the direction of rotation, or it will not generate. The direction of rotation of a motor depends on the connection of its fields and armature, and it can be reversed by reversing either of these, but not both. When a motor runs in a certain direction, a certain relation exists between the directions of the currents in its armature and field; when either of these currents is reversed, it changes this relation and with it the direction of rotation; but when both are reversed, which corresponds simply to changing the polarity of the dynamo that runs the motor, the relation remains the same and so does the direction of rotation. Exchanging the places of the terminals applied to a motor (unless it is separately excited) will not change its direction of rotation. For given armature and field connections, a shunt machine will run in the same direction as a motor that it does as a dynamo; a series machine will run in the opposite direction in the two cases, while the direction in which a compound-wound machine will run as a motor depends on the relative strength of the two windings and on the conditions under which the motor is started.

### FIELD-COIL TROUBLES.

**35.** Fields, like armatures, are subject to troubles of various kinds; they are liable to open circuits, short circuits, and grounds. An open circuit can give rise to various effects, depending on the conditions under which the machine operates and also on the style of machine. In the case of a series dynamo, an open circuit in the field will render it totally incapable of operating either as a mòtor or a dynamo, but no harm can come to the machine itself, unless the fault should take place while the current was on, in which case it would be apt to burn a hole in whatever happened to be around the break.

**36.** On a shunt machine, the amount of trouble caused by the opening of a field coil depends on whether the machine is a motor or a dynamo; and if a dynamo, on whether it runs alone or in multiple with other dynamos. If the machine is an isolated dynamo, a break in the field coil can do no further damage than to prevent the machine from generating and, hence, cut off the current from whatever lamps or motors may be operated by it. If, however, the dynamo is in multiple with other dynamos on the same load, the result of such a fault will be that the other machines will send a large rush of current back through the faulty machine and cause, practically, a short circuit.

**37.** Series dynamos are not, as a rule, run in multiple. If a shunt dynamo that is ordinarily run as a dynamo is made to run as a motoı by current being backed through it, it will keep on running in the same direction, but will spark at the brushes, owing to the fact that the brushes are in a place suited to dynamo running and not to motor running. If the dynamo is compound-wound, the direction that it will try to run when it becomes a motor depends on the position of its brushes and mainly on' the relative strength of the series windings and shunt windings. Breaking the field of a dynamo in multiple with other dynamos amounts to the same thing practically as breaking the field on a shunt motor.

Breaking the field of a shunt motor destroys its counter E. M. F., so that there is no opposition to the line E. M. F. and there is practically a short circuit through the armature. As the field magnetism dies down slowly, the counter E. M. F. dies down also, and the short circuit does not take place so quickly but that the faulty machine may acquire a very high rate of speed and throw its belt or do other damage before the fuse or circuit-breaker acts.

**38.** An open circuit in the field of a shunt motor in action, then, results in a short circuit, abnormal speed, throwing off the belt, and opening the circuit-breaker. On a compound-wound motor connected accumulatively, the speed will not reach such a high value, because the series coils hold it down; but if the motor is differentially connected, as soon as the shunt field breaks, the series coils opposed to it bring the motor to a stop and start it up in the opposite direction. If the fault should occur while the motor is standing still, it would be impossible to start a simple shunt motor with a safe current. A compound-wound motor will, if the starting current is large enough, start up on the field provided by the series-turns; but it will start up in the wrong direction if the series coils are so connected as to oppose the shunt coils.

**39.** The effect of the reversal of a single field coil on a machine depends on how many field coils the machine has, in other words, the more poles a machine has, the less will be the effect of an irregularity in one of them. If the machine has only two coils and one of them is incorrectly connected, the machine will not start as a motor and it will not generate as a dynamo. If there are four field coils, it will take a heavy current to start it as a motor, and the brushes will spark even while the motor is starting. As a dynamo, most machines will refuse to pick up their fields at all, except at very high speeds, and even if separately excited, the voltage at normal speed will be below its proper value. On machines of more than four field coils, the same symptoms hold good, but to a less degree, and are characterized by sparking at the brushes that include the faulty field.

**40.** One other fault producing effects very much like the above is loose joints in the magnetic circuit. Where a machine has two halves fitting together, great care should be taken that no particles of foreign matter are allowed to get in the joint and so introduce an air gap into the magnetic circuit. The same precaution holds good in regard to machines having detachable pole pieces. The effect of a loose, or open, joint in the magnetic circuit, as in the case of a reversed field coil, is to weaken the field of the machine, so that on a dynamo there will be trouble picking up the field at normal speed, and the open-circuit voltage will be reduced by an amount dependent on the seriousness of the fault; while on a motor the starting current will be greater and the speed higher than it should be.

The effects are aggravated where the dynamo or motor is running in multiple with others. If a dynamo, it will be unable to meet the requirements of the rush hours, because its voltage cannot be increased enough to make it claim its share of the total load; it will require close hand regulation under varying loads, because its voltage will not vary at the same rate as that of its neighbors, although it may be the same kind of a machine. The best illustration of the condition applied to motors in multiple is found on an electrically propelled car where the two or more motors are practically rigidly connected within certain limits of load. The motors when doing their heaviest duty are in multiple, and the one whose path offers the least resistance takes the most current. The motor that has a reversed field coil or a loose, or open, joint in its steel frame, has a lower counter E. M. F., and hence has less apparent resistance; it will then be only a matter of time when this motor will cause the car to repeatedly blow its main fuse. The motor will become hotter than its mate, the brushes will spark, the commutator will blacken and become rough, the armature throw solder, and a final inspection will probably show that all the cotton insulation on the field wire is baked or charred.

**41. Short Circuits in Field.**—The action of a short circuit in a field coil depends on the kind of machine, the manner in which the field coils are connected, and whether the short circuit is a good or bad contact. Take a shunt dynamo, with four field coils; if the coils are in series, as in Fig. 11 (*a*), so that the voltage across each coil is only one-fourth of the total voltage, a good short circuit in a single coil will cause it to run comparatively cool, while the remaining coils will get unusually warm. A bad contact is apt to emit more or less of an odor of burning shellac and other insulation. The cutting out of a single coil in four will reduce the resistance of the field circuit so that more current may flow through the remaining coils in an attempt to make up the loss of magnetism due to the cutting out of one coil, but this automatic compensation will not be so much but that the field rheostat resistance will have to be lessened to keep up the dynamo voltage.

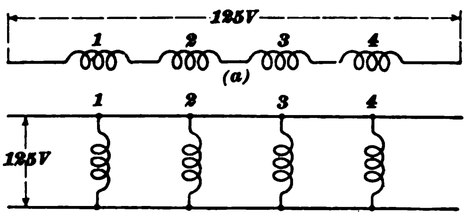

FIG. 11.

**42.** On the other hand, if the shunt coils are all in multiple, as shown in Fig. 11 (*b*), the faulty coil will be the one to get hot and the rest of the coils will run at normal temperature. If the fault is such as to cut out the coil entirely, the machine will loose its field, because a shunt machine will not support a field on short circuit. On a compound-wound dynamo running alone, a short circuit in the shunt winding will cause about the same symptoms, as far as the heating goes, as in a shunt machine. If the shunt coils are in multiple and connected as shown in Fig. 12 (*a*) (*short shunt* connection), the dynamo will drop its field if one shunt coil is dead short-circuited; but if the shunt coils, as a whole, are connected as shown in Fig. 12 (*b*) (*long shunt* connection), so that the series coils are in series with the

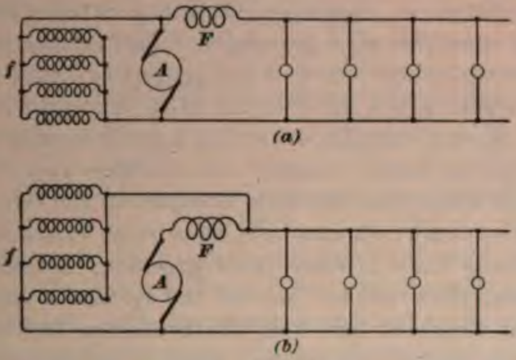

FIG. 12.

fault, the dynamo will throw its belt because the series coils work under the best possible conditions — a short circuit.

**43. Moisture in Field Coils.**—Moisture in field coils will cause them to heat and make the brushes spark. Before putting such fields into actual service, they should be baked out, either with the current or in an oven. Moist field coils, as a rule, steam when hot, feel moist to the hand, and their insulation to the frame of the machine measures low. The most refined way of locating a short-circuited field is to measure the resistance of the field suspected and compare it with that of a standard field of the same kind. A variation of over 10 per cent. should not be allowed, and where the fields are in multiple, not over 2 per cent. variation should be allowed. A short-circuited shunt field can be located by short-circuiting or cutting out one field coil at a time and measuring the open-circuit voltage of the dynamo.

**44. Grounded Field Coils.**—A grounded field is a very common source of trouble in some classes of work, but a very unusual one in others. Commercial circuits may be divided into two classes, namely, *metallic-return* and *ground-return circuits*. On metallic-return circuits, both the outgoing and return wires are insulated from the earth. Ordinary lighting and conduit trolley systems are examples of metallic-return circuits. Ordinary street-railway systems are examples of a grounded circuit, since the trolley wire constitutes one side and the ground or track the other. The indications of a grounded field depend on whether the machine is on a metallic-return or a ground-return system, and if on the latter, whether the machine is a dynamo or motor and what place the field occupies in the circuit.

Metallic-return systems are, as a rule, characterized by having very little trouble from grounds; because, in the first place, since neither side of the system is permanently grounded, there is but half the tendency for either side to ground; and in the second place, a single ground does not at all disturb the operation of the devices, because another ground is necessary to complete the circuit. Should two grounds develop, one on each side of the circuit, or at two places in a device, a short circuit follows; but, as a rule, a single ground can be detected and removed before another occurs to cause trouble. Lightning is responsible for many of the grounds on metallic-return circuits. Inasmuch as ground troubles are more common on ground-return circuits, we will devote our limited space to this class of work.

**45.** Fig. 13 shows a shunt dynamo at work on a grounded circuit, the ground return being indicated by the dotted line. Suppose a ground takes place at *a*; the result will

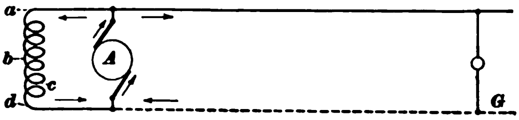

FIG. 13.

be a dead short circuit across the line, under which condition the dynamo will drop its field. A ground at *d* will have no effect, as that side of the circuit is already grounded. A ground anywhere between *a* and *d* will cut out a part of the field and severely heat the part not cut out.

**46.** Fig. 14 shows a compound-wound dynamo with the shunt field connected inside of the series field. A ground at *a* will cause the dynamo to drop its field as before; a ground at *d* will not be felt. A ground at *b* will cut out a part of the field and the remaining part will heat badly; the voltage on the line will drop. Fig. 15 shows a compound-wound dynamo with the shunt connected across the terminals of the machine instead of across the brushes. This alters the conditions very much. A ground at *a* establishes a short circuit through the series field. The shunt field is cut out entirely and the line loses its power, but, owing to the strong current in the local circuit *A–F–a–d–A*, the dynamo throws its belt unless the circuit-breaker acts quickly. A ground at *b* will give the same indication as in the case of Fig. 14.

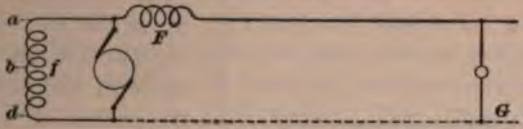

FIG. 14.

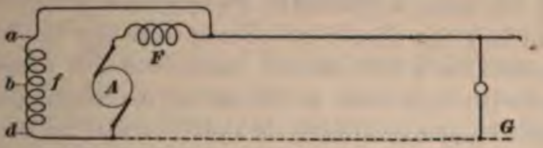

FIG. 15.

**47.** Fig. 16 shows a series dynamo at work on a grounded circuit. A ground anywhere on the field will cut the power off the line. A ground anywhere near *a*, unless the dynamo is of the arc-light type with very heavy armature reaction, will throw the belt. A ground anywhere near *b* will simply cut out the field and the machine will stop generating.

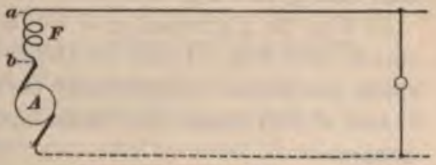

FIG. 16

Fig. 17 shows a series machine as in Fig. 16, but with the field next to the ground. A ground at *a* will cause the dynamo to stop generating; a ground at *b* might cause it to drop its voltage and it might not, depending on the amount of resistance in the load; if this resistance is small, the dynamo will generate a lower voltage. A ground at *d* will not be felt.

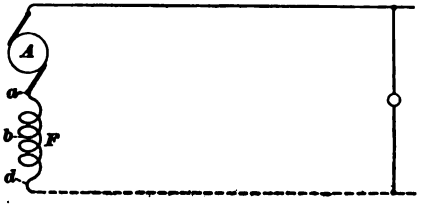

FIG. 17.

**48.** Let us suppose now that the dynamo in each of the above figures becomes a motor; the current, instead of coming from within the machine, comes to it from an outside source. In Fig. 13, then, a ground at *a* when the machine is running will cut out the motor so that it can get no power, the circuit-breaker will fly out or the motor will throw its belt, owing to the fact that in virtue of its momentum it will become a dynamo running on short circuit, both ends being grounded, one permanently and the other through the fault. The effects for the other grounds will be about the same as in the case of the dynamo.

In Fig. 14, a ground at *a* will cut out the shunt field and stop the motor very suddenly, as the armature will be grounded at both ends, and the series coils will be heavily charged by the current passing through the fault. The machine will really become a separately excited dynamo on short circuit. A ground at *b* will cause part of the field to heat badly, and a ground at *d* will have no effect.

In Fig. 15, a ground at *a* will cause practically the same action as in Fig. 14 and for about the same reason. In both cases, the motor will probably throw its belt. A ground at *b* and *d* will cause the same action as in the case of the dynamo.

In Fig. 16, a ground almost anywhere on the field, except at *a*, will separately excite a part of the field and bring the armature to a sudden stop, owing to its dynamo action through the short circuit. A ground at *a* can cause no action of this kind, because the dynamo has no shunt field; and although the armature is permanently grounded on one end and is grounded through the whole series field on the other end, it cannot generate, because a series machine runs in opposite directions as dynamo and motor, for given connections; so that the direction in this case is not the right one. The motor of Fig. 16 finds its practical parallel in the street-railway motor as it is today. Fig. 17 is the same thing, only the fields are next to the ground, so that a ground in a field coil does not cut out the armature.

In Fig. 17, a ground at *a* cuts out the field and the entire short-circuit current passes through the armature, causing violent sparking that burns the brushes and commutator. A ground at *b* cuts out all the field below it, weakening the field and causing the armature to take an excessive amount of current. A ground at *d*, as in former cases, has no effect at all. Placing the field next to the ground has the disadvantage that a ground may take place in such a part of the field that the armature may be overloaded a long time before the fact is known; but it has the advantage that, being on the negative side of the armature, the difference of potential between the positive side of the field and the ground is very small, so that there is not as great a tendency for grounds to develop as in the first case. It is a well-known fact that cars equipped with motors whose fields are next to the ground give much less trouble from grounded fields than cars whose fields are next to the trolley.

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## REASONS FOR A DYNAMO FAILING TO GENERATE.

**49. Loss of Residual Magnetism.**—Among the many causes which may make a dynamo fail to generate, loss of residual magnetism is often one of the most troublesome. The magnetism that remains in the steel or iron frame after the field current is cut off is called **residual magnetism,** and every dynamo must have a certain amount of this to start on before it can build up its field. As a rule, dynamos leaving the factory retain enough residual magnetism to start on, but there are several ways in which they can lose it; they sometimes lose it after having given no previous trouble of that sort in months or years. Some dynamos never lose their residual magnetism, or **charge**, as it is called, while others seem to have a weakness for doing it.

In many cases the peculiar action cannot be explained; in some cases it may be due to any of the following conditions: (*a*) Excessive vibration; hence, the dynamo should always rest on a solid foundation. (*b*) To the earth's magnetism; where practicable it may be well to set the machine so that its north pole is toward the north; then the earth's magnetism will pass through the machine in the same direction as its own. The earth's magnetism is very weak, but when assisted by vibration it may sometimes be sufficient to counteract the residual magnetism. Only two-pole machines can be really set to fill this condition, as on multipolar machines the poles radiate in all directions. (*c*) A dynamo set very near another dynamo; in such a case, stray lines of force from a loaded dynamo may thread their way through the magnetic circuit of an idle one in the reverse direction and neutralize its residual magnetism. (*d*) The fields accidentally given a slight flow of current in the wrong direction; this can very easily occur on a compound-wound or series dynamo, as current from the outside will always pass through the series coils in the opposite direction to that in which the current from the machine itself would pass. In shunt machines, however, this is not so, for as a motor, the field winding shunts both the armature and the line. (*e*) The machine started up with the fields or armature as a whole incorrectly connected, that is, reversed; in this case the result will be to destroy whatever residual magnetism there may have been. (*f*) The field circuit broken too suddenly; when a field circuit is suddenly broken, the residual magnetism is sometimes brought down to zero or even reversed.

**50.** Where a dynamo has lost its charge, the pole pieces will have little or no attraction for a piece of soft iron. There are several ways in which the charge may be restored. Series dynamos seldom lose their charge so entirely that they will fail to pick up a field on short circuit. Where a compound-wound dynamo refuses to pick up a field with its shunt field, it can often be made to pick up by disconnecting the shunt coils and short-circuiting the machine through a small fuse that will prevent damage due to the short circuit. The same idea in a modified form may be used on a plain shunt dynamo by temporarily connecting all the shunt coils in multiple instead of series. This makes the machine a series dynamo with a low-resistance circuit. Any machine can in many cases be made to pick up a field by simply short-circuiting the armature by holding a piece of copper wire across the brushes or by rocking the brushes back from their neutral position. The effect is to make the magnetism of the armature help the field to build up.

If none of these expedients produce the desired result, the fields must be recharged from an outside source. If the dynamo runs in multiple with other dynamos, this is an easy matter; it is only necessary to lift the brushes or disconnect one of the brush-holder cables on the dead machine and throw in the main-line switch, the same as if the machine were going into service with the others. The fields will then take a charge from the line and their polarity will be correct. After the field has been charged, the brushes or cable must not be moved until the main-line switch is open, because a short circuit will be made. If the dynamo does not run in multiple with another and there is a dynamo within wiring distance, disconnect the shunt field of the dead dynamo and connect it to the live circuit. The live circuit may be the trolley wire of a street-railway circuit. Bear in mind, however, that this is a 500-volt circuit, so that if it is to be used for charging 125-volt fields it must be applied for only a couple of seconds. There have been cases where it has been necessary to run a couple of wires a quarter of a mile, or more, to obtain current for charging a field. If there are absolutely no other means available for charging, several cells of ordinary battery must be used; connect the field coils in series with the cells in series and give the pole pieces of the dynamo repeated knocks with a hammer while the charging is going on; if this fails, reverse the terminals of the battery and repeat the operation—it may be that the first time the battery is applied its magnetizing force opposes what little residue magnetism there may be in the iron. As a last resource, when all other available sources fail, connect the fields so as to obtain the least possible resistance, put them in series with the armature through a small fuse, and speed the armature considerably above the normal rate. Very often a dynamo, instead of losing its residual magnetism, will acquire one of a reversed polarity, due, perhaps, to the same causes exercised to a greater degree. Except where the dynamo is used for charging storage cells, or for electroplating, or for running arc lamps, or for running in parallel with other machines, the reversal of its polarity can do no harm. In case an arc machine is reversed, the concave carbon will be the bottom one and most of the light will be thrown up instead of down, where it is generally desired.

**51. Wrong Connection of Field or Armature.**—Every dynamo requires that a certain relation exist between the connection of its field and armature and its direction of rotation, or it will refuse to generate. Suppose a dynamo to be generating; if its field or armature connection (either, but not both) be reversed, it will be unable to generate; or if all the connections be left intact and the direction of rotation reversed, the machine will be rendered inert. Not only is it unable to generate with the wrong connections or rotation, but a short run under this condition will render the machine unable to generate after the conditions are corrected, unless the field is recharged, because the effect is to destroy its residual magnetism.

Let us see why such is the case. It sometimes happens that when a dynamo is first started it has a small E. M. F. due to the residual field; but upon closing the field circuit, the E. M. F. falls to zero and the machine refuses to generate. Such action indicates a wrong connection of field or armature for the given direction of rotation and can be explained as follows: Suppose the dynamo to be properly connected and to be generating; this implies that the field current is in such a direction as to produce a magnetic field that reinforces the residual field. Now, without disturbing anything else, let the field terminals be reversed; for the sake of clearness, we will suppose that there remains a residual field due to the current last flowing. Under this condition, the lines of force due to the residual field are in the same direction as they were when the machine was properly connected and generating; the small current now generated in the armature, and due to the residual field, will be in the same direction as it was then, but the field connections being reversed, the current flows around the poles in such a direction as to neutralize their residual magnetism. The weak residual field is now opposed by this new field and soon the residual field is reduced to zero, thus totally depriving the machine of all ability to pick up. Nor can a reverse field, even if established by recharging, be maintained; for, assuming a reversed residual magnetism to be provided, the lines of force have changed direction, the armature current does likewise, and previous conditions being reestablished, the residual field is again destroyed. If, then, a dynamo fails to generate, and all other conditions are apparently correct, reverse the field leads and again try to make the dynamo generate. If a loss of residual magnetism is indicated by very weak poles, recharge the fields.

**52. Open Circuits.**—A series dynamo cannot, of course, pick up its field if any part of the circuit is open, for there is but one circuit. It cannot pick up its field if the resistance of its outside load is above a certain value peculiar to each machine, for as a rule series dynamos supply devices that are also in series, and every device added means more resistance for the machine to pick up through. As it will not pick up through a high resistance, it is customary to provide series dynamos with a switch, by means of which the line and machine are short-circuited at starting, so that the load is not thrown on until the dynamo picks up, after which the short-circuiting switch is opened, leaving the line properly connected to its terminals. A shunt, or compound-wound, dynamo will not pick up if the shunt field circuit is open; the open circuit may be in the field itself, in the field rheostat, or in some of the wires or connections involved in the circuit. A careful inspection will generally disclose any fault that may exist in a wire or connection; to find out if the rheostat is at fault, short-circuit it with a piece of copper wire; if the dynamo generates with the rheostat cut out, the fault is in the rheostat. To find out if the open circuit is in a field coil, use a test-lamp circuit or a magneto-bell to test the coils one at a time. Before doing so, be certain that all communication is cut off between the machine under test and the line, if there are other machines on the same circuit. In making this test, bear in mind that if the dynamo is compound-wound and connected as shown in Fig. 15, an open circuit in the series coils will cut off the current from the shunt coils also.

Connecting wires, in course of time, are liable to be shaken loose or broken by vibration; they should be made of flexible cable, and the screws that hold them may be secured against turning by means of a drop of solder. A field circuit is sometimes held open by a defective field switch that, to all appearances, is all right; repeated burning will oxidize the tip of the blade and make a blister on it; the blister will not carry current and it will press the jaws of the switch apart so that only the blister touches, and so opens the circuit. Another trivial but common cause of open circuits is the blowing of fuses. Fuses of the enclosed type give more trouble in locating the fault than any other kind, because it cannot be told by looking at them whether the fuse is intact or not.

An open circuit in the armature will interfere with the proper generation of the current, but such a fault, as a rule, announces its own occurrence in a very emphatic manner and does not, therefore, require to be looked for. A very uncommon source of open circuit, where copper brushes are used, is due to the burning of the brush heels into oxide. The dynamo will refuse to pick up until the brushes are trimmed and cleaned. When an armature just from the factory refuses to generate where the one just taken out has been generating, the trouble is probably due to either of two causes: There may be shellac on the commutator—in this case, a little coarse sandpaper will set things right; the armature may be a right-hand armature while the one taken out was wound left-hand, or *vice versa*. The expressions right-hand and left-hand here apply to features of winding or connecting, and should such a condition arise, it can be remedied by reversing the armature or field connections, or the direction of rotation.

Before attributing the failure of a dynamo to generate to any of the above open-circuit causes, see that the brushes are on the commutator, the field switch closed, and the greater part of the field rheostat cut out.

Always bear in mind that the E. M. F. generated when a machine is started up is very small because the residual magnetism is weak. It may not require a complete open circuit in the field to prevent the machine picking up. A bad contact that might not interfere with the working of the machine when it is up to full voltage might be sufficient to prevent its picking up when started. A loose shunt wire in a binding post or a dirty commutator will introduce sufficient resistance to prevent the machine from operating. Trouble is very often experienced in making machines with carbon brushes pick up, especially if the brushes or commutator are at all greasy. If such is the case, thoroughly clean off the commutator, wipe off the ends of the brushes with benzine, and see that they make a good contact with the commutator surface. Metal brushes, if kept in good order, do not give as much trouble as carbon in this respect, because their contact resistance is lower.

**53. Short Circuits.**—A short circuit on the line will make a shunt dynamo drop its field, but the dynamo may throw its belt before it does so. With a short circuit on the line, a shunt dynamo will not, therefore, pick up its field. Such a short circuit may be due to some fault in the pilot-lamp circuit, or it may be due to a motor switch being left in across the line by one of the outside consumers. On this account, it is to the interest of any company supplying power for motors to see that every motor is provided with an automatic cut-out, so that when the line voltage goes below a certain value the motor circuit will open. With a series or compound-wound dynamo, a short circuit on the line increases its ability to generate, because the fault is in series with the series coils and its large current passes through them. A series dynamo, like a shunt dynamo, will not pick up if the field is short-circuited. A compound-wound dynamo will not pick up on open circuit if the shunt field is short-circuited; it will pick up with an open circuit in the main circuit, but will not hold its voltage under load if the series coils are short-circuited. In some cases a shunt dynamo will not pick up on full load, as this realizes too nearly the condition of a short circuit; so that to be on the safe side, it is best to let the machine build up its field before closing the line switch.

Short circuits within the dynamo itself generally give rise to indications that point out the location and nature of the fault. In any event, the first thing to find out is whether the fault is in the dynamo or out on the line; if it will pick up its field when the line switch is opened, but fails to do so with it closed, the trouble is outside of the dynamo. It may be on the switchboard, where a workman may have left a tool or piece of wire lying across the bus-bars. The most common method used to get rid of a cross on the line is to burn it out; this is done by centralizing the entire dynamo capacity of the station, if necessary, on the faulty circuit.

**54. Brushes and Brush Holders.**—In order for any direct-current dynamo to generate, its brushes must be in a certain position that depends on the type and design of the machine. As a rule, the design of the brush holder gives a clue as to where the brushes should sit, but one cannot say to a certainty where the brushes on a given dynamo should go unless he is familiar with that particular machine, because the position of the brushes is governed by conditions of winding and connecting not apparent to the eye. If the connections were brought straight out from the armature to the commutator bars, the brushes would always sit in line with the center of the space between the polar horns, because this is the position of the neutral field. But very often, for reasons of accessibility, the wires coming from the coils are given a **lead** that brings the normal position of the brushes in line with the centers of the pole pieces. The brushes on a motor sit the same as those on a dynamo, except that on a motor they are given a little lead backwards (in the opposite direction to that in which the armature rotates), while on a dynamo they are given a little lead forwards.

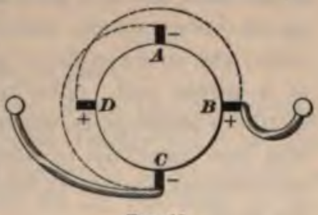

FIG. 18.

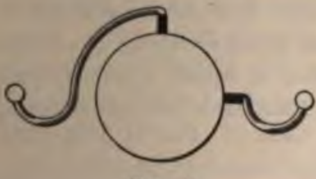

FIG. 19.

Fig. 18 refers to a four-pole machine with four brushes. The proper position for the brushes in this particular case is that shown in the diagram. *A* is on top, *B* to the right, *C* on the bottom, *D* to the left. If the rocker-arm be given a quarter turn to the right or left, so that, say, *A* takes the place of *B*, *B* the place of *C*, *C* the place of *D*, and *D* the place of *A*, it amounts to the same thing as reversing the armature cables or terminals, and the dynamo will refuse to generate.

Fig. 19 also refers to a four-pole armature, but it is so connected that only two sets of brushes are needed, and these two brushes are shown in the position where it is most natural to expect to find them. Fig. 20, however, shows where, for reasons of accessibility, symmetry, and safety, the brush holders are generally found in practice.

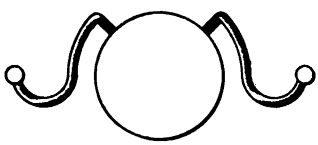
FIG. 20

**55. Field Coils Opposed.**—Failure to generate may be due to one or more field coils being incorrectly put on, or connected, so that they oppose each other. The only thing to do is to locate the faulty coil and reverse its connection. On a compound-wound dynamo, the reversal of a shunt-field coil will generally keep the dynamo from picking up on open circuit, unless the dynamo has more than four coils; the more coils it has, the less effect has the reversal of a single coil. The reversal of a series coil is not felt until an attempt is made to load the machine; the voltage will not come up to where it should for a given load and the brushes are apt to spark on account of the weakening of the field.

**56. Low Speed.**—No dynamo will pick up its field below a certain speed, but with the field once established, the machine will hold it at a much lower speed than that required to establish it. The speed at which a series dynamo will pick up depends on the resistance of the external circuit.

**57.** Among the causes of failure to generate not included in the above are faults in the iron circuit, loose or open joints in the frame proper or between the pole pieces and the frame. Such imperfections also lower the maximum voltage of the dynamo. An armature core undersize or pole pieces bored out too large will cause the same trouble. There is one peculiar case on record where an extra armature was shipped from the factory and when put in the dynamo refused to generate. The trouble was located in the armature core, which was found to be $\frac{5}{32}$ inch too small in diameter and an inch too short. The armature was given a running test before it left the factory, but it was run as a motor, and as no speed reading was taken, the mistake was not noticed. Occasionally orders become confused in the shipping department and the armature goes out with the wrong pulley; if the pulley is too large, the difference in speed will affect the picking up of the dynamo. Finally, it is possible to send out a 125-volt armature with 250-volt fields, or a 250-volt armature with 500-volt fields; in such a case it is only necessary to connect the fields in multiple to make the dynamo generate, if it should so happen that the voltage of the armature is the voltage wanted.

### MOTOR FAILS TO START.

**58.** When a motor fails to start when the controlling switch is closed, any one of several things may be the matter. There may be an open circuit, a short circuit, a wrong connection, the power may be off the line, or the trouble may be purely mechanical. If the failure to start is due to an open circuit or to absence of power on the line, there will be no flash when the switch is closed and opened again. To tell if there is any power on the line, test with incandescent lamps or a voltmeter. If the fault is an open circuit, it may be found in any of the following places: Defective switch; broken wire or connection in the starting box; loose or open connection in some of the wiring; shellac on the commutator; a piece of foreign matter under one brush; brush stuck in the holder or no brush in it at all; brush springs up; fuse blown; some wire, apparently all right, broken inside of the insulation; or an open circuit in some part of the motor itself. Any of these sources of open circuit may be located with a magneto-bell or with a lamp or bell circuit. If the trouble is due to a short circuit, there will be a flash when the starting box is thrown off.

**59.** Among the more common sources of short circuit, are these: Short-circuited armature coils; short-circuited commutator; short-circuited field coils; field on a shunt or compound-wound motor connected so that the armature cuts out the field winding; carbonized brush yoke; brushes in the wrong position. If the armature coils or commutator are short-circuited, the machine may start and turn over part way and stop again. With a field coil short-circuited, the armature will start only under a heavy current, with accompanying sparking, and will acquire a high rate of speed.

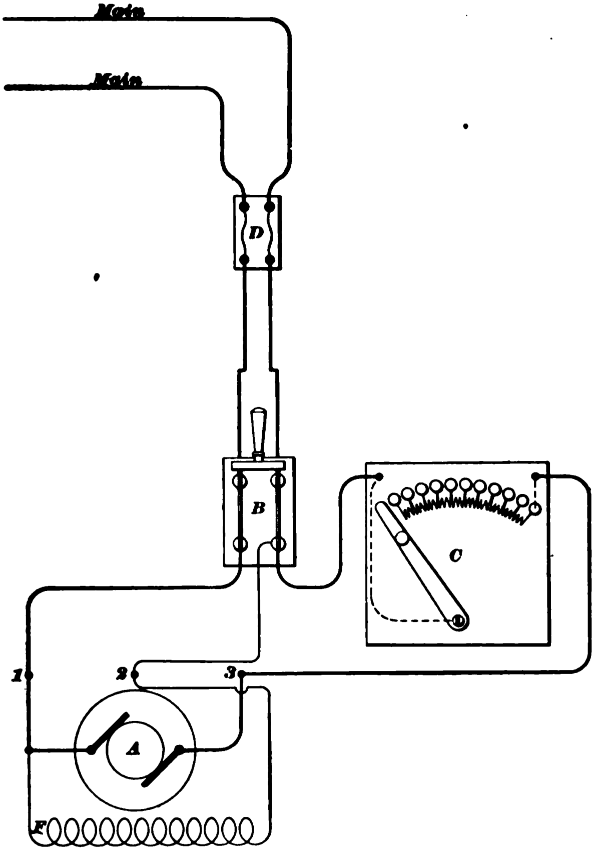

FIG. 21.

**60.** Fig. 21 shows the correct method of connecting a shunt motor with an ordinary starting box. Shunt motors are usually equipped with three terminals, *1*, *2*, *3*. Terminal *1* takes one armature lead and one end of the shunt field; terminal *2* the other end of the shunt; and terminal *3* the other end of the armature. By examining the figure it will be seen that *2* is connected ahead of the rheostat, so that as soon as the main switch *B* is thrown in, the shunt field is excited from the mains. Then when the handle of *C* is moved from the off position to the first point, the current that flows through the armature has a strong field to react on and the motor starts up with a good torque. Fig. 22 shows the motor wrongly connected. In this case, the wire running from post *2* is connected between the rheostat and the motor instead of being connected between the main switch and the rheostat; in fact, it is equivalent to connecting posts *1* and *2* together. The result is that the shunt field is connected to the armature terminals and no current will flow through it until the starting-box lever is moved over. As soon as the starting-box lever is moved, current flows through the armature, but very little flows through the field because the pressure across the field terminals is only equal to the drop in the armature. The result is that the field is very weak and the motor refuses to start until the starting lever is moved so far over that a very large current flows through the armature. The box becomes excessively hot, and if the fuses or circuit-breaker do not give way, there is danger of something being burned out.

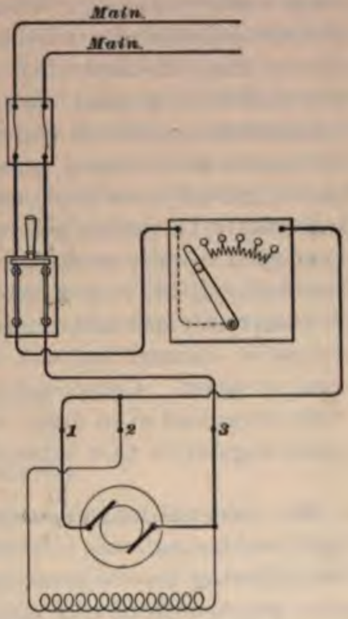

FIG. 22.

**61. Wrong Motor Connections.**—Wrong connections may be classed under two heads, *internal* and *external.* External wrong connections involve confusion of wires running to and from the motor, and are most likely to occur where a reverse switch must be used to change the direction of rotation of the armature. Such errors as getting an armature wire in where a field wire should go, or *vice versa,* come under this head. Where field and armature leads are of the same kind and are brought out through a closed motor frame, they should be felt out by hand, for this is where the confusion is most apt to take place. Wrong internal connections, as far as the man that assembles and sets up the motor is concerned, are confined to the field coils. If a motor has only two field coils and one of them is connected incorrectly, the motor will not start at all unless the starting current is so enormous that the armature itself magnetizes the field. If the motor has four coils and only one of them is incorrectly connected, the machine will start up under excessive current, but will spark badly and acquire a high rate of speed. Compound-wound motors with the series coils connected in to assist the shunt coils will not give the speed regulation that some classes of work require.

**62. Mechanical Troubles.**—Among the purely mechanical troubles that may interfere with the starting of a motor, the following may be mentioned: *Too much load; loose pole piece down on the core, or bearings worn until core is let down on the pole pieces; sprung armature shaft with the same result; hot box; tight belt; want of end play in the armature; some piece of foreign matter between the core and the pole piece, or between the pinion and the gear, if the motor is geared to its work.* In many cases, a motor can operate many more machines than it can start; it should be a rigidly enforced rule that all machine tools operated by the motor should have their shifters thrown over when the day's work is done. There is no excuse for an armature being let down on the pole pieces through wear in the bearings; they should be closely watched and close track kept of the time of last renewal. A loose pole piece not only restrains the armature mechanically, but it weakens the motor field and lessens the starting power. A sprung armature shaft is liable to occur at any time, and may be due to a suddenly imposed overload, a sudden reversal, or a hot box. A bent shaft is visible to the eye and causes the machine to make a noise. It should be taken out at once. Want of end play may be the fault of the maker or of the operator; on every shaft there are two shoulders that take the thrust of the bearings and limit the end play. Sometimes an armature will turn freely when cold, but when it becomes hot and expands it will bind on the collars. The end play must be limited or there will be knocking, so that if in renewing a set of bearings longer ones are put in than were taken out, the end-play problem is liable to arise. Bearings should always be turned to gauge. Belts should be long enough to allow of sag in the slack side, which should run on top. This improves the area of pulley contact and lessens the tension required to prevent slipping.

## SPARKING.

**63. Sparking** at the brushes may be due to any of the following causes: *Too much load; brushes improperly set; commutator rough or eccentric; brushes making poor contact; dirty brushes or commutator; too high speed; sprung armature shaft; low bearings; worn commutator; short-circuited or reversed armature coil; high-resistance brush; vibration; belt slipping; open-circuited armature; weak field; grounds.*

**64. Too Much Load.**—In this case the armature heats all over. The sparking may be lessened but not stopped by shifting the brushes ahead on a dynamo and back on a motor. If the machine is a motor, the speed will be low; if a dynamo, the voltage will be below the normal amount. In both cases the pulley is apt to get warm through slipping of the belt.

**65. Brushes Improperly Set.**—Brushes may be out of their proper position in either of two ways: they may be the right distance apart but too far one way or the other as a whole; this can, of course, be remedied by shifting the rocker-arm back and forth until the neutral point is found. The brushes may, as a whole, be central on the commutator, but too far apart or too close together. Such a fault must be remedied by adjusting the individual holders. On two-pole machines the two sets of brushes are placed diametrically opposite each other. On four-pole machines having two sets of brushes, the distance between the centers of the two sets should be just one-fourth of the circumference of the commutator. On four-pole machines having four brushes, they should set on the quarter; the best and quickest way to get this set in position is to place two sets at diametrically opposite points, the two remaining sets then go half way between them. In any case, for all commutator machines that are not special, the distance between the centers of adjacent sets of brushes should be the total number of commutator bars divided by the number of poles.

**66. Commutator Rough or Eccentric.**—A commutator will become rough either as a result of abuse or as a result of bad selection of the copper and mica of which it is made. If the mica is too thick or too hard, it will not wear as fast as the copper and will stand out in ridges. If too soft, it will eat out and make a furrow between bars that will catch carbon or copper dust and create local short circuits. An eccentric commutator acts like a bent shaft and may be the result of faulty workmanship or the result of a hard blow. In either case it must be turned true, but before doing it be certain that the commutator is at fault and not the shaft.

**67. High or Low Bar.**—A high or low commutator bar causes a clicking sound to be emitted whenever it passes under the brush. A high bar can often be removed with a file, but a low bar requires that the whole commutator be turned off.

**68. Brushes Making Poor Contact.**—Poor brush contact may be due to any one of several causes. The brush may be stuck in the holder; the temper may be out of the tension spring; the brush hammer may rest on the side of the holder and not on the brush; the brush may not fit the surface of the commutator; the holder may have shifted to the wrong angle. New brushes should be sandpapered to fit the commutator; the hammer should rest over the slot that guides the brush, so that when the brush wears it will follow it down. Tension springs should be paralleled by a conductor attached to the brush, so that the current will not flow through the springs and take the temper out of them.

**69. Dirty Brushes or Commutator.**—Carbon brushes are liable to give out paraffin when hot, which, getting on the commutator, insulates it in spots. The paraffin is also liable to mix with carbon dust and coat the brush with a non-conducting, sticky substance. A copper brush is apt to get clogged with oil, dust, and threads of waste (waste should never be used on a commutator). Brushes should be kept trimmed and cleaned. Dirty commutators, as a rule, are the result of using too soft a brush.

**70. Too High a Speed.**—A machine is apt to spark if its speed is too high, because it interferes with the commutation.

**71. Sprung Armature Shaft.**—A sprung armature shaft causes the commutator to wabble, giving very much the same symptoms as an eccentric commutator, and great care must be taken not to confuse a sprung shaft with an eccentric commutator.

**72. Low Bearings.**—On some types of machine, excessive wear in the bearings throws the armature far enough out of center to distort the field and cause sparking. Modern machines intended to stand fluctuating loads are so designed that there is no danger on this account.

**73. Worn Commutator.**—When a commutator wears down below a certain point, even if otherwise in good condition, it seems inclined to spark in spite of everything that can be done. It may be because the brushes then span more bars, because the bars become thinner as they wear away, or it may be because an error in the angle of the holder increases with the distance from the commutator. The effect is most noticeable on some street-railway motors where it is almost impossible to run together two motors whose commutators differ greatly in size. The brush holder should be kept as near the commutator as possible, as it not only enables the bars to be counted off more accurately, but it holds the brushes at a short leverage and prevents chattering.

**74. Short-Circuited or Reversed Armature Coil.** Either of these faults will cause a local current to flow, with the result that either a dynamo or a motor will require an unusual amount of power to run it even when unloaded. The reversed coil can be located by sending current through the coils one at a time and holding a compass over them. A short-circuited coil can be detected by holding a piece of iron up to the head of the armature while it is running; there will be a decided pulsation of the iron once each revolution. Also, a motor will run with a jerky motion especially noticeable at low speeds, and the voltmeter connected to a dynamo will fluctuate. Such a fault may be due to a cross in the coil itself or contact between two commutator bars. In either case, unless the cross is removed, the coil will burn out.

**75. High-Resistance Brush.**—Up to a certain point, high resistance in a carbon brush is a good feature, and that is why they are used. But it is possible to get the resistance so high that the brush will spark on account of its inability to carry the current at the contact surface. Such a brush will get very hot and will be slowly chewed off at the wearing end.

**76. Vibration.**—A shaky foundation will cause the whole machine to vibrate and will cause it to spark steadily, which fault can be remedied only by placing the machine upon a firmer foundation.

**77. Belt Slipping.**—A slipping belt will cause intermittent sparking because it subjects the machine to unusual variations in speed.

**78. Open-Circuited Armature.**—By an open-circuited armature is meant a break in one of the armature wires or its connections. Excessive current may burn off one of the wires or a bruise of some kind may nick a wire so that the normal load or less burns it off. A commutator may become loose and break off one or more leads. In any case there are two very characteristic symptoms of an open-circuited armature: a ball of fire runs around the commutator and the mica is eaten from between the bars to which the faulty coil is connected, the bars themselves become dark, pitted, and burned on the edges. Sometimes, on account of abuse, the armature throws solder and all the commutator connections become impaired. In such a case there are no actual open circuits, but there are a series of poor contacts that result in making the commutator rough and black, pitting the bars and eating the mica.

**79. Weak Field.**—A weak field may be due to a loose joint in the iron circuit, to a metallic short circuit in the field coils, to opposition of the field coils, or to the fact that heat has carbonized the insulation on the field coils so that the current short-circuits through it. Any of these influences decrease the number of lines of force that cross the armature, with the result that the starting power of the motor is decreased, and the speed and current are increased. On a dynamo, the E. M. F. and the ability to pick up are decreased.

**80. Grounds.**—On a metallic-return circuit, a single ground has no effect, but two grounds can so take place that the whole or any part of the field or armature may be cut out; such a pair of grounds is nothing more nor less than a short circuit and it falls under that head. On a ground-return circuit, a ground anywhere except in the armature has, as a rule, but one indication: there is a flash and the armature burns out.

## ALTERNATING-CURRENT MACHINERY.

### ALTERNATORS.

**81.** The points given in regard to installing and handling the parts of direct-current machines hold good in regard to alternators. On account of the higher voltages used and the peculiar nature of the alternating current, abrasion of insulation through careless handling is apt to cause more serious trouble than on the lower voltage direct-current devices.

Alternating-current dynamos may be self-exciting or separately excited. As a rule, on account of the flexibility of control they are separately excited from a direct-current machine either coupled to the shaft of the alternator itself or run from an independent agent. In some cases the separate excitation is assisted by a current from the machine itself, this current being rectified by means of a commutator fixed on the shaft. The main and important advantage of separate excitation is that attendants are not called on to handle devices carrying the high voltage of the alternator in their ordinary duties of regulation.

Fluctuations of the voltage may be caused by slipping of the belt of the alternator or that of the exciter. This is one point in favor of directly connected machines with the exciter on the same shaft. All chance of fluctuation due to belt slipping on the exciter is then eliminated. As with any other separately excited machines, the direction of rotation of an alternator is immaterial as far as generation is concerned, but due regard must be had for the brushes on the rings and commutator if the machine has a rectifier.

Where there are two or more alternators to be run in multiple that are not excited from dynamos coupled to their own shafts, it is a good idea to excite them all from the same dynamo. The exciting plant should consist of at least two like units so wired that either can be used, which should be used alternately to insure that both are kept dried out and in good working order. Each alternator field can then be controlled by means of a resistance box in series with it. Alternator armatures are constructed along such simple and substantial lines that they give few of the petty troubles incidental to direct-current practice. Most of the trouble lies in the exciter and its circuit, so that the service of the alternator as a whole is influenced by all the troubles likely to arise in any direct-current circuit. If the exciter is out of order, so is the alternator; if the exciter breaks down, so does the alternator, unless provision is made for quickly throwing in a second exciter. If the exciter belt slips or its brushes spark or either the iron or copper part of the field circuit is impaired, the voltage of the alternator goes down.

Where the machine is alone on a circuit, it is started in the same way as any other isolated dynamo; it is brought up to speed, the field excited by closing the field circuit, and the voltage regulated with the field rheostat. To shut down, the same operations are gone through in the reverse order. Alternating-current machines have a great deal of self-induction; some of them have so much that even on a short circuit the current is not large enough to burn them out. On account of this great self-induction, a dynamo should not be unnecessarily subjected to violent variations in load. For example, if the circuit of an alternator is suddenly opened under full load, the high induced E. M. F. is liable to puncture the insulation and cause a breakdown.

**82. Alternators in Parallel.**—When alternators are operated in parallel with one another, they must all run at such speeds that their currents will be in step with one another; that is, the several currents must vary in unison with one another, all the currents coming to their maximum values at the same instant. When this condition exists, the machines are said to be *in synchronism;* and before one alternator is thrown in parallel with another, the attendant must make sure that the machine to be thrown in is in synchronism with those already in operation. This is usually indicated by synchronizing lamps or by a synchronizing voltmeter. Some synchronizing lamps are connected so that they go out when the machines are in step, while others are connected so that they light up. The attendant should always be sure as to just which way they are connected before he attempts to throw the machines in parallel. After the alternators are running together smoothly, their loads are adjusted by varying the field excitation.

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### ALTERNATING-CURRENT MOTORS.

**83. Alternating-current motors** call for the same general care as dynamos. Like all other dynamo machinery, they must be kept clean. Alternating-current machinery is generally operated at high pressure, and cleanliness is, therefore, absolutely necessary. In stations, it will pay to pipe compressed air to the machines and use a strong blast for blowing the dust and dirt out of the windings. Most of the motors in common use are of the synchronous, or induction, type.

**84. Synchronous Motors.**—These are the same in general construction as alternators. They are not intended to start up under load, but will run up to speed when connected to the line. In doing so they take a fairly large current, and in some cases, therefore, are brought up to synchronism by some outside source of power—as, for example, a small induction motor—before being connected to the line. Synchronous motors are separately excited and, in fact, are almost the same throughout as a separately excited alternator.

**85. Induction Motors.**—These motors are used for most work where the motor must frequently be started or stopped or where a good starting effort is required. In fact they are used for about the same kind of work as ordinary direct-current motors. There is nothing about them that requires any special care, that has not already been mentioned, after they are once installed. As a matter of fact, as they are inherently self-starting and have no commutator to give trouble, they require fewer precautions and less judgment on the part of the operator than direct-current machines. At starting there is a tendency to permit an excessive flow of current; this not only strains the machine electrically, but on account of the great armature reaction, which weakens the field, the starting power is also decreased. The starting current is, therefore, limited by means of resistance. This resistance takes either the form of a stationary rheostat placed in the circuit of the armature through collector rings, or it is in the form of a resistance placed within the body of the armature and operated either by means of a lever operating a switch concentric with the shaft or automatically by centrifugal force.

The direction of rotation of a two-phase motor can be reversed by reversing the leads of either phase; that of a three-phase motor by reversing any one of the phases, thereby reversing the magnetic rotation of the field.

**86.** Many of the smaller sizes of induction motors are started by simply throwing in the main switch, but with the larger sizes, this gives too great a rush of current. When a starting resistance is used, it should be cut out rather slowly in order to give the machine time to gain speed. On the other hand, the starting resistance should not be left in too long, or there will be danger of overheating the motor. Never use a starting resistance for the purpose of regulating the speed. This applies to all motors, direct or alternating. Starting resistances are designed to carry current for a short time only, and if current is allowed to flow through them continuously they will be burned out.

**87.** Another method of starting induction motors that is used considerably is by means of what is called a **starting compensator.** This is a device inserted between the motor field and the line, and serves to cut down the voltage applied to the motor at starting, thus preventing a rush of current.

Fig. 23 shows the connections for one of these starting compensators. *A* is a double-throw switch, *B*, *B*, *B* the line wires, and *C* the motor. In this figure the arrangement is shown for a three-phase motor. *E*, *E*, *E* are the coils wound on a laminated iron core similar to a transformer core. For a two-phase starter only two coils are necessary. These coils are provided with a number of taps, so that the compensator may be adjusted for different starting requirements. The switch is shown in the starting position, and by following out the connections it will be seen that one section of the coils is in series between the line and the motor field. One circuit, for instance, may be traced from *m* to *s* through *m*–*n*–*o*–*p*–*r*–*s*, when the switches are in the starting position. The E. M. F. developed in that portion of the coil between *p* and the adjustable contact *o* opposes, and hence decreases, the line voltage and allows the motor to start up gradually. After the motor is under headway, the switch is thrown up to the running position and one circuit may be traced through *m*–*n*–*r*–*s*. This cuts out the coils and connects the motor directly to the line. The operation of starting usually requires about 15 seconds for motors of moderate sizes. Always be sure that the starting device, no matter what kind it may be, is in circuit with the motor before throwing the main switch.

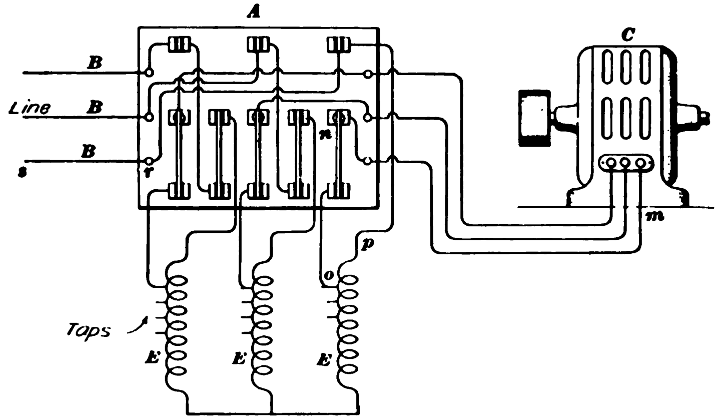

Fig. 23.

## ROTARY TRANSFORMERS.

**88. Rotary transformers,** or converters, are used either to change alternating current to direct current or direct current to alternating. In most cases they are used to change alternating current to direct current, and when used to change from direct to alternating, they are often called **inverted rotaries.**

Rotary transformers combine the features of both direct-current machines and alternators, but on account of their peculiar nature a number of special points come up in connection with them that are not to be found with ordinary direct-current or alternating-current machines. The construction of the machine itself is very similar to that of a direct-current dynamo. The armature is provided with a winding in the same manner as the armature for a direct-current machine and this winding is connected to a commutator. The winding is also connected to collector rings, which serve to deliver alternating current to the machine. For example, when the rotary is used for changing alternating current to direct current, the alternating current is led into the armature winding by means of the collecting rings and is commuted, or changed, to a direct current, which is delivered to the lines attached to the brushes on the direct-current side. If direct current is supplied at the commutator, it flows through the windings and is changed to an alternating current, which is delivered from the collector rings. Rotary transformers when taking current from alternating-current lines run as synchronous motors, i. e., they run in step with the generator that drives them and their speed cannot change unless the speed of the generator changes. They may be run in parallel on either the direct-current or alternating-current sides.

**89. Starting Rotary Transformers.**—There are a number of different methods used for starting rotary transformers, and the one adopted will depend very largely on the conditions under which the machine is used. The following are some of the methods commonly used:

(*a*) *Starting from the Alternating-Current Side.*—When the machine is to be started from the alternating-current side, the fields are left unexcited and the armature is thrown into connection with the line through a starting resistance. The machine then starts and runs up to synchronism, but in so doing takes quite a large current from the line. The machine starts as an induction motor by virtue of the currents induced in the pole faces by the currents in the armature. After the rotary has come up to speed, the field switch is closed. Another method is to have a small induction motor connected to the shaft of the main machine. This motor is started from the line and runs the large machine up to synchronism. The large machine is then thrown in, and it can thus be started without using an excessive line current. As soon as the rotary is running, it excites its own fields from the direct-current side.

(*b*) *Starting from the Direct-Current Side.*—When a rotary is already in operation in a station and it is desired to start up another, the simplest way is to start up the rotary as a shunt-wound direct-current motor by first seeing that its fields are separately excited and then inserting a resistance in the armature circuit and gradually cutting it out as the machine comes up to speed, like any other direct-current motor. In many stations where storage batteries are used, the rotaries are started by using direct current from the batteries, because they furnish a source of direct current that is always available whether other rotaries are running or not. Another very good method for supplying direct current for starting or exciting purposes is to equip a station with a small direct-current dynamo directly connected to an induction motor. When starting a rotary as a direct-current shunt-wound motor, always be sure that the field is excited before connecting the armature, also see that under no circumstances is the field circuit broken while the machine is running as a direct-current motor. If the above happens, the machine will race, and cases are on record where rotary converters have been almost completely wrecked from this cause. Of course, where the machine is run from the alternating-current end, it runs in synchronism and the breaking of the field circuit will not result in racing. On the whole, however, starting with direct current is the preferable method.

(*c*) *Starting from the Alternator.*—This method of starting rotaries can only be used in comparatively few cases. It consists in connecting the rotary to the line and then starting the alternator in the distant station from which the rotary is operated. As the alternator comes up to speed, so does the rotary. This is a good method where it can be used, and especially where the rotaries are of large size.

(*d*) Another common method of starting is to have a small induction motor attached to an extension of the shaft of the rotary. This motor will start up readily when supplied with alternating current, and after it has brought the rotary up to speed it is cut out.

**90. Hunting of Rotary Converters.** — Sometimes rotary converters give a great deal of trouble due to what is known as *hunting*. The converter does not run uniformly, but develops a periodic variation in speed that causes wide fluctuations in the direct-current voltage. Excessive sparking is liable to result, and in some cases the effects have been almost as bad as a short circuit. This trouble has been particularly noticeable on converters made to operate at a fairly high frequency, say in the neighborhood of 60 cycles per second. Rotary converters are now generally operated on the lower frequencies, such as 40 or 25 cycles per second. When a machine hunts, the field shifts back and forth across the pole pieces, thus changing the position of the neutral field and giving rise to very bad sparking. The governor on the engine driving the alternator may be responsible for the hunting in the first place, or it may be caused by variations in the load, or by the influence of other machines on the same system. Its effects can be remedied to a considerable extent by putting heavy copper bridges between the pole tips and by surrounding the pole face with a heavy copper ring. If the field then shifts back and forth, it will set up heavy currents in the ring, or bridges, and these currents will tend to oppose any shifting of the field.

## TESTING FOR FAULTS.

**91.** Many of the defects that are liable to arise in connection with dynamos and motors are, of course, apparent from a mere inspection of the machine. Other defects, such as short-circuited or open-circuited field coils, short-circuited or open-circuited armature coils, etc., must be located by making tests. Many of these tests have already been referred to, and the following is intended to show how they are carried out. For tests of this kind Weston or similar instruments are most convenient if they have the proper range for the work in hand. For measuring resistances, the *drop-of-potential method* is generally most easily applied. This method consists in sending a known current through the resistance to be measured and noting the pressure between the terminals of the resistance; in other words, noting the pressure required to force the known current through the unknown resistance. The resistance may then be determined at once from Ohm's law, because $C = \frac{E}{R}$, or $R = \frac{E}{C}$. If the resistance to be measured is very low, as, for example, an armature coil, the voltmeter must be capable of reading low and a millivoltmeter (one reading to thousandths of a volt) will be best suited to the work. Of course, a good Wheatstone bridge may also be used for measuring resistances, but it is generally not as convenient to use around a station as the drop-of-potential method.

**92. Testing for Open-Circuited Field Coils.**—If a machine does not pick up, it may be due to the absence of residual magnetism. If any residual magnetism is present, a voltmeter connected across the brushes will give a small deflection when the machine is run up to full speed, so that this point can easily be determined before a test is made for a broken field coil. Examination of the connections between the various coils will show if they are defective or loose; quite frequently the wire in the leads from the spools becomes broken at the point where the leads leave the spool, while the insulation remains intact, so that the break does not show. This may be detected by "wiggling" the leads.

If the break is inside the winding of one of the coils, it can only be detected by testing each coil separately to see if its circuit is complete. This may be done with a Wheatstone bridge or with a few cells of battery and a galvanometer. A low-reading Weston voltmeter makes a good galvanometer to use for this purpose.

If the current from another dynamo can be obtained, the faulty spool may be detected by connecting the terminals of the field circuit to the terminals of the circuit of the other machine; no current will flow through if the circuit is broken, but if a voltmeter is connected across each single field coil in succession, it will show *no deflection* if the coil is continuous, because both poles of the voltmeter will be connected to the *same* side of the dynamo circuit. If the coil has a break in it, one of its terminals will be connected to one side of the circuit and the other to the other side, so that a voltmeter connected between these terminals will show the full E. M. F. of that circuit. Consequently, when the voltmeter is connected across a spool and shows a considerable deflection, that spool has an open circuit which must be repaired before the dynamo can operate.

This method of testing is represented by the diagram, Fig. 24; *1*, *2*, *3*, and *4* represent the field coils of a four-pole dynamo, there being a break in coil *2* at *B*. The terminals *a* and *e* of the field winding are connected to the + and − terminals of a "live" circuit; that is, a circuit connected to a dynamo in operation. It will be seen that terminals *a* and *b* of coil *1* are both connected to the + side of the circuit, and as there is no current flowing through the field circuit, there is no difference of potential between *a* and *b*;

therefore, a voltmeter connected to *a* and *b*, as at *V*, will show no deflection. But terminal *c* of coil *2* is connected to the − side of the circuit; so a voltmeter connected to *b* and *c*, as at $V_1$, will show a deflection, and, in fact, will indicate the difference of potential between *a* and *c*.

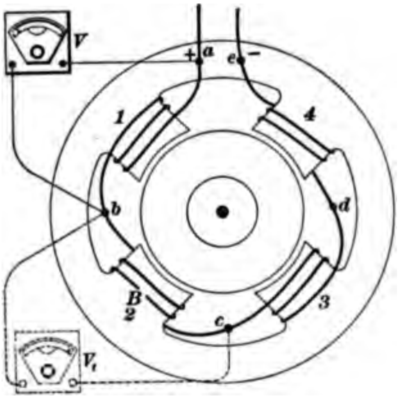

FIG. 24.

The above test may be roughly made with a bit of wire long enough to span from terminal to terminal of a coil. If one end of the wire is touched on *a*, for instance, and the other on *b*, it will not affect the circuit; but if it is touched on the terminals of the coil in which the break is located, the field circuit will be completed through the bit of wire, and a spark will occur when the wire is taken away. The wire should not be allowed to span more than one coil at a time, otherwise it may short-circuit so much of the field winding that too great a current will flow.

**93. Short-Circuited Field Coil.**—It is evident that if the windings of a field coil become short-circuited, either by wires coming in contact or by the insulation becoming carbonized, the defective coil will show a much lower resistance than it should. The drop of potential across the various field coils should be about the same for each coil, so that if one coil shows a much lower drop than the others, it indicates a short circuit of some kind.

**94. Test for Grounds Between Winding and Frame.** After the machine has thoroughly warmed up, it should be tested for "grounds," or connections between the winding and the frame or armature core. This may best be done with a good high-resistance voltmeter as follows: While the machine is running, connect one terminal of the voltmeter to one terminal of the dynamo, and the other terminal of the voltmeter to the frame of the machine, as represented in Fig. 25, where $T$ and $T_1$ are the terminals of the dynamo, and $V$ and $V_1$ two positions of the voltmeter, connected as described above.

If in either position the voltmeter is deflected, it indicates that the field winding is grounded somewhere near the *other* terminal of the dynamo; that is, if the voltmeter at $V$ shows a deflection, the machine is grounded near the terminal $T_1$, and *vice versa*. If the needle shows a deflection in *both* positions, but seems to vibrate or tremble, the armature or commutator is probably grounded. If in either case the deflection does not amount to more than about $\frac{1}{20}$ the total E. M. F. of the machine, the ground is not serious, but if the deflection is much more than this, the windings should be examined separately, the ground located, and, if possible, removed.

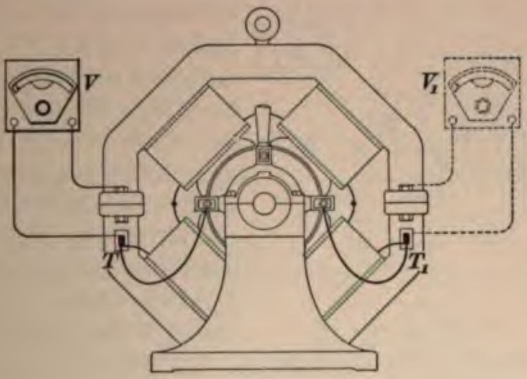

FIG. 25.

**95.** To locate the ground, if thought to be in the field coils, each coil should be disconnected from its neighbor (with the machine shut down, of course) and "tested out" by connecting one terminal of another dynamo (or of a "live" circuit) to the frame of the machine, care being taken to make a good contact with some bright surface, such as the end of the shaft or a bolt head, and the other to a terminal of the coil to be tested, through a voltmeter, as represented in Fig. 26.

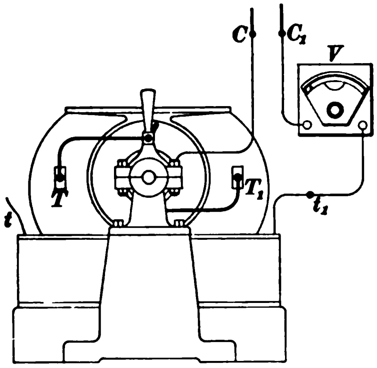

FIG. 26.

Here $C$ and $C_1$ represent the terminals of a "live" circuit, which should have a difference of potential between them about equal to the E. M. F. of the machine when it is in operation, but not greater than the capacity of the voltmeter will allow of measuring. $T$ and $T_1$ represent the terminals of the dynamo, as before, and $t$ and $t_1$, the terminals of the field coils, which have been disconnected from each other and from the dynamo terminals. One terminal $C$ of the circuit is connected to the frame of the machine; the other terminal $C_1$ of the circuit is connected through the voltmeter $V$ to the terminal $t_1$ of the field coil. If that coil is grounded, the voltmeter will show a deflection about equal to the E. M. F. of the circuit $C$ $C_1$, but if the insulation is intact, it will show little or no deflection. The wire connecting the voltmeter with the terminal $t_1$ may be connected in succession to the terminal of the other coil, or coils, and to the commutator; any grounded coil of the field or armature winding will be shown by a considerable deflection of the voltmeter needle.

**96.** If the machine tests out clear of grounds, it should be shut down after the proper length of time and the various parts of the machine felt over to locate any excessive heating. If accurate results are wanted, thermometers should be used, placing the bulb on the various parts (armature, field coils, etc.) and covering it with a wad of waste or rags. They should be looked at from time to time until it is seen that the mercury no longer rises, when the point to which it has risen should be noted. A thermometer hung on the wall of the room will give the temperature of the air, and the difference between the air temperature and that of the various parts of the machine should not exceed the prescribed limit.

**97. Test for Defects in Armature (Bar-to-Bar Test).**—Faults in armatures may best be located by what is known as a **bar-to-bar test.** This consists briefly in sending a current through the armature (in at one side of the commutator and out at the opposite side) and measuring the drop between adjacent bars all around the commutator. If the armature has no faults, the drop from bar to bar should be the same for all the bars. The connections for this test are shown in Fig. 27. *E* is the line from which the current for testing is obtained and *L B* a lamp bank by means of which the current flowing through the armature may be adjusted. Connection is made with the commutator at two opposite points *A*, *B*. A contact piece, or crab, *C* is provided with two spring contacts that are spaced so as to rest on adjacent bars. These contacts are connected to a galvanometer, or

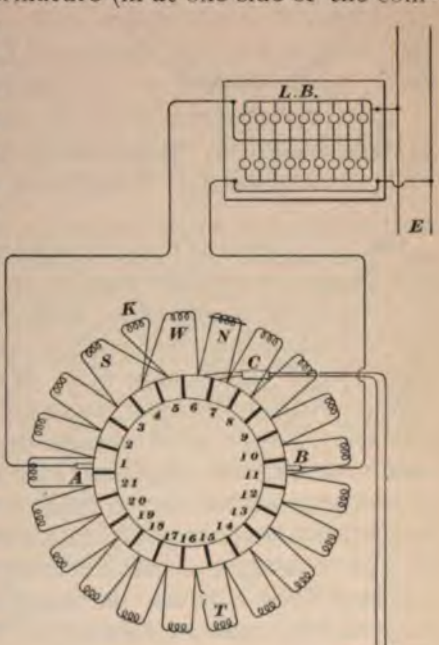

FIG. 27.

millivoltmeter, *G*. For the sake of illustrating the way in which the bar-to-bar test will indicate various kinds of faults, we will suppose that in coil *N* there is a short circuit, that the commutator leads of coils *S*, *K*, and *W* have been mixed, as shown, and that there is an open circuit in coil *T*. Current will flow through the top coils from *A* to *B*, but not through the bottom coils on account of the open circuit at *T*. Terminals *A*, *B* may be clamped permanently in place by means of a wooden clamp, or a strap such as shown in Fig. 28 may be used.

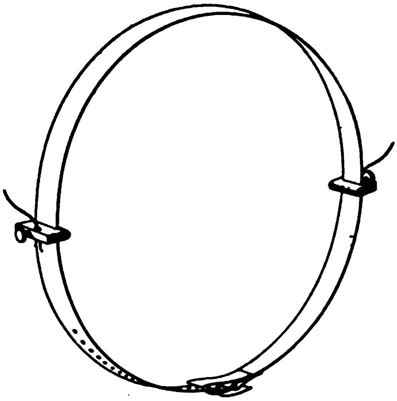

FIG. 28.

**98.** It is evident that the deflection of the galvanometer will depend on the difference of potential between the bars. If everything is all right, practically the same deflection will be obtained all around the commutator, no matter on what pair of bars *C* may rest. The test is carried out as follows: Adjust the lamp bank until the galvanometer, or voltmeter, gives a good readable deflection when *C* is in contact with what are supposed to be good coils. The amount of current required in the main circuit will depend on the resistance of the armature under test. If the armature is of high resistance, a comparatively small current will give sufficient drop between the bars; if of low resistance, a large current will be necessary. The operator runs over several bars and gets what is called the standard deflection and then compares all the other deflections with this. In case he should start on the damaged part, he will find when he comes to the good coils a difference in deflection.

If the contact rests on bars *3*, *4*, it is easily seen that a deflection much larger (about double) than the standard will be obtained, because two coils are connected between *3* and *4* in place of only one. When on *4* and *5*, the deflection of the voltmeter, or galvanometer, would reverse, because the leads from *K*, *S*, and *W* are crossed. The deflection would not be greater than the standard, because only one coil is connected between *4* and *5*. Between *5* and *6* a large deflection will be obtained for the same reason that a large one was obtained between *3* and *4*. Between *6* and *7* little or no deflection will be obtained, because coil *7* is here represented as being short-circuited and, hence, there will be little or no drop through it. As *C* is moved around on the lower side, no deflection will be obtained until bars *15* and *16* are bridged. There will then be a violent throw of the needle, because the voltmeter will be connected to *A* and *B* through the intervening coils. When *C* moves on to *16* and *17*, there will again be no deflection, thus locating the break in coil *T*. As a temporary remedy for this, bars *15* and *16* may be connected together by a "jumper" or piece of short wire.

**99.** If any of the coils have poor or loose connections with the commutator bars, the effect will be the same as if the coil had a higher resistance than it should and, hence, the galvanometer deflection will be above the normal. In practice, after one has become used to this test, faults may be located easily and rapidly. It is best to have two persons, one to move *C* and the other to watch the deflections of *G*.

**100. Locating Short-Circuited Armature Coils.** Where there are a large number of armatures to be tested, as, for example, in street-railway repair shops, an arrangement similar to that shown in Fig. 29 is very convenient for locating short-circuited coils. *A* is a laminated iron core with the polar faces *b*, *b* (in this case arranged for four-pole armatures). This core is wound with a coil *c* that is connected to a source of alternating current. The core is built up to a length *d*, about the same as the length of the armature core. The core *A* is lowered on to the armature, and when an alternating current is sent through *c* an alternating magnetization is set up through the armature coils.

This induces an E. M. F. in each coil; and if any short circuits exist, such heavy local currents are set up that the short-circuited coils soon become hot or burn out, thus indicating their location. If an armature with a short-circuited coil is revolved in its own excited field, the faulty coil promptly burns out, so that this constitutes another method of testing for such faults. To cut out a short-circuited coil, temporarily disconnect its ends from the commutator and bend back the ends out of the way and tape them so that they cannot touch each other and put a short piece of wire, or "jumper," in place of the coil so disconnected. It is always best, however, to replace the defective coil, because if the turns are short-circuited on each other, the coil may persist in heating and thus damage other coils.

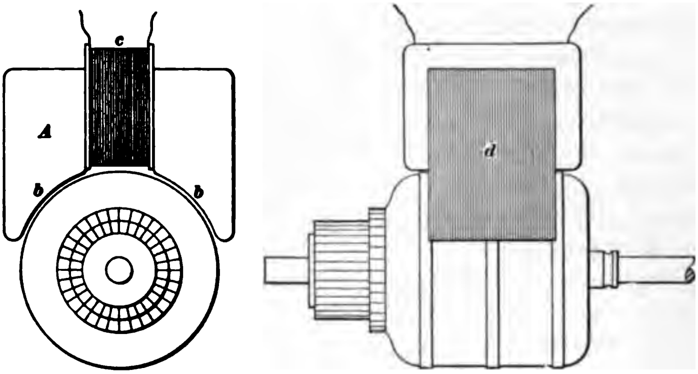

FIG. 29.

### RHEOSTATS FOR TESTING PURPOSES.

**101.** When tests are being made on machines, some form of adjustable resistance is necessary in order to get a variable load. If the current to be handled is not large, a lamp bank is very convenient, since the resistance may readily be changed by cutting lamps in or out. Another very convenient form of resistance for testing purposes may be made by slitting a sheet of ordinary roofing tin into strips, as indicated in Fig. 30, and attaching this sheet to a wooden frame. The strips should be from ½ inch to ¾ inch wide, and the sheet should be slit to within ⅛ inch on alternate edges, so that when it is stretched out and held in position, it will form one continuous conductor. The resistance may be adjusted by a sliding crosspiece *S*, which short-circuits any required amount of resistance. Frames of this kind can be made of different current capacities depending on the width of strip used.

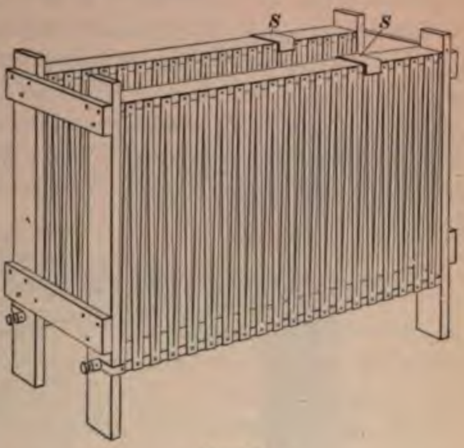

FIG. 30.

**102. Water Rheostat.**—When heavy currents are to be handled, a **water rheostat** is convenient. This usually consists of a wooden tank filled with salt water, in which are hung two iron (or other metal) plates that are attached to the terminals of the dynamo. The circuit is thus completed through the water between the plates, and, by varying the distance between the plates, the resistance of the external circuit can be adjusted between wide limits.

An old oil barrel makes a good tank if the dynamo to be tested has an output of not more than about 15 kilowatts. If a greater amount of energy must be disposed of, the surface and the amount of the water must be greater than a barrel will afford, and a tank should be made for the purpose, especially if several machines are to be tested. Fig. 31 illustrates a form of water rheostat, in which *T* is the wooden tank, which should be about 7 feet long and about 2½ feet square, inside measurements, made of 1½-inch or 2-inch pine plank, with tongued-and-grooved joints that should be leaded to make them tight, the whole being held together by cross bolts, as represented in the figure.

Two iron rods *R*, *R* are placed across the top of the tank, to which are attached the terminals of the dynamo circuit, as represented at *W*, *W*. From these rods two iron plates *P*, *P* are hung, which should have about 3½ or 4 square feet of surface (on one side) below the water level. These plates may be made of a couple of pieces of old boiler plate or heavy (¼-inch or thicker) sheet iron, cut with two projecting lugs on the top, which are bent into hooks by which the plates are hung from the rods *R*, *R*. Cast iron will do equally well; two old ash-pit doors, for example, will make very good plates, the rods being passed through the holes for the hinge pins. When ready for use, the tank should be filled with water, and from 5 to 20 pounds of rock salt or washing soda added to reduce the resistance to the required figure, as water alone will give altogether too high a resistance.

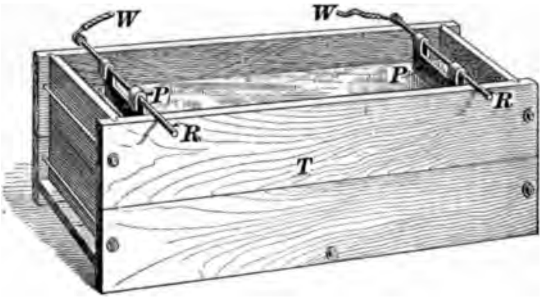

FIG. 31.

# DYNAMO-ELECTRIC MACHINERY.

## CONSTANT-CURRENT DYNAMOS.

**1.** If an ordinary series-wound dynamo is connected to an external circuit whose resistance is variable, both the current and the E. M. F. will vary. For example, if the external resistance is increased, the current will be diminished; as the machine is series-wound, this weakens the field, which lowers the E. M. F. and still further decreases the current. If the external resistance is decreased, the current and E. M. F. will each be increased.

In order to obtain a constant current in a circuit of variable resistance, it is necessary, then, to vary the E. M. F. of the machine as the resistance changes, and in the same proportion. There are many different devices for accomplishing this, as will be described.

In general, the field magnets of constant-current dynamos may be bipolar or multipolar, with salient or consequent poles, according to the ideas of the designer. They are usually series-wound. The armature windings, however, may be divided into two classes, *closed coil* and *open coil.*

### CLOSED-COIL ARMATURES.

**2. Closed-coil armatures** have already been described in connection with constant-potential dynamos. Ring armatures are generally used in constant-current dynamos, on account of their good ventilation, and from the ease with

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which any damaged coil may be repaired, since a coil can be replaced without disturbing others, which is not the case in the usual form of drum windings, where the coils overlap.

**3.** The methods used to regulate the E. M. F. of closed-coil armatures are as follows: (1) Varying the speed; (2) varying the strength of the field; and (3) shifting the brushes.

The first method is seldom used, though in special cases it is very convenient. The principle of this method is that with a simple series-wound dynamo, if the external resistance is increased, decreasing the current and E. M. F., the speed may be increased until the E. M. F. rises to a point where it will force the normal current through the external circuit; if this adjustment of the speed is made as rapidly as the external resistance changes, the current will be maintained at a constant value.

**4.** The second method has already been described in connection with series-wound dynamos. It is evident that this same principle may be applied to constant-current machines, so as to properly vary the E. M. F. The range of this method of regulation is quite limited, because the strength of the field cannot be economically forced beyond the point where the iron begins to be saturated, and if it is much reduced, the armature reaction (which is constant, since the current is constant) will cause the neutral point to considerably alter its position.

**5.** The third method is almost universally used in this type of machines. It has already been pointed out that the greatest difference of potential in a (bipolar) closed-coil armature exists between the two opposite coils that are in the neutral spaces; so, to get this maximum difference of potential between the brushes, they are placed on the opposite commutator segments that are connected to these two coils. Now, if the brushes are shifted from this position, although the E. M. F. generated in the armature is not altered, the *difference of potential between the* *brushes is reduced;* for, although the circuit through the armature winding is still divided into two parts connected in parallel between the brushes, the separate E. M. F.'s of all the coils in each of the two parts are not all in the same direction.

**6.** If there were no armature reaction, shifting the brushes to a point half way around the commutator from the neutral space would reduce the difference of potential between them to zero; and in positions between these two, the difference of potential would be proportional to the amount of shift. Since the coils short-circuited by the brushes would be moving in strong magnetic fields, there would also be violent sparking.

There is, however, a very considerable armature reaction in dynamos of this type, which is so proportioned with respect to the strength of the field that it has two effects. One is to shift the neutral point so that the difference of potential between the brushes is not quite proportional to the amount of shift; but this is of little importance compared to the second effect, which is that the tendency of the current in the armature winding to form consequent poles at the points where the current enters or leaves the winding through the leads to the commutator actually *forces the lines of force of the field from the armature at these points*, leaving only a weak field to influence the short-circuited coil. By proper proportioning of the armature winding, this results in little or no sparking at the brushes, especially as the amount of current in a constant-current machine seldom exceeds 10 amperes, which allows the use of such a narrow brush that the time during which a coil is short-circuited is so short that the current in the coil does not have time to become large enough to cause serious sparking.

The brushes may be shifted by hand to get the desired regulation, but as this would require constant attention, it is usual to shift the brushes automatically by devices on or near the dynamos. These devices are usually controlled about as follows: Electromagnets are connected in the

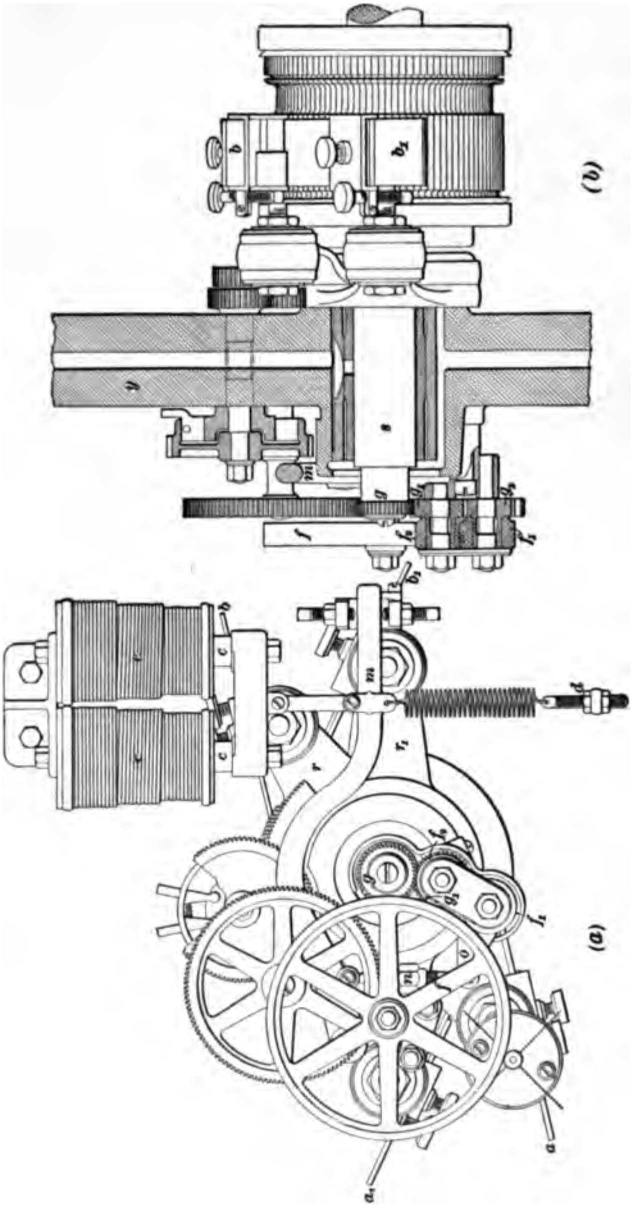

FIG. 1.

main circuit and are so adjusted that when any change in the external resistance causes the current to increase or decrease from normal, the corresponding movement of the magnet keeper mechanically connects the rocker-arm of the dynamo to some sort of driving mechanism, so that the brushes are properly shifted. When they reach such a point that the current is again at its normal value, the electromagnet (usually called the *controlling magnet*) disconnects the rocker-arm from the driving mechanism, and the motion of the brushes ceases until some change in the external circuit calls for a new adjustment.

The mechanical parts of the various brush-shifting devices are quite different in the different makes of constant-current machines. In the following description of the principal features of some of the best known types of closed-coil, constant-current machines, the types of regulating devices used will be taken up more in detail.

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## PRINCIPAL CLOSED-COIL CONSTANT-CURRENT DYNAMOS.

**7. Wood Dynamos.**—These machines have bipolar, consequent-pole, series-wound field magnets and ring-wound armatures of quite large diameter.

A regulator that has been used largely on these dynamos is shown in Fig. 1 (*a*) and (*b*). To reduce the sparking to a minimum, it has been found desirable to use two positive brushes $a$, $a_{11}$, shown only in (*a*), located a little distance apart on the commutator, and two negative brushes $b$, $b_{11}$, located opposite the positive brushes. The brushes are mounted on opposite ends of the rocker-arms $r$ and $r_1$, so that simply shifting these two effects the shifting of the four brushes. The angle between the rocker-arms $r$ and $r_1$ of each pair of brushes is variable, preserving a distance between the bearing ends of the brushes equal to about three commutator segments at light loads (low E. M. F.), and about double this at heavy loads (high E. M. F.). This variation in distance is accomplished by shifting the *back* brushes $a_1$

and $b_1$ of each pair a little faster than the front brushes *a* and *b* are shifted, so that the back brush gradually overtakes the front one, lessening the distance between them, in shifting from the heavy-load to the light-load position.

The electromagnet *e* is connected in series with the armature, field, and external circuit, and furnishes the power for regulating the current. The cores *c*, *c* of this electromagnet are free to move into or out of the coils, the attraction of the magnet being balanced by a tension spring provided with an adjustment at *d*. The lever arm *m* is raised by the electromagnet when the current increases and is lowered when the current weakens. A small gear *g* on the end of the shaft continuously drives two friction rollers $f_1$, $f_2$ in opposite directions by means of the gears $g_1$, $g_2$. The movement of the lever arm *m* presses the friction wheel *f*, by means of the intermediate links *n*, *o*, against one or other of the friction rollers, thereby turning the friction wheel in a forward or backward direction. This motion is then communicated by means of gearing to the rocker-arms, producing the relative movement already referred to. The two positive and the two negative brushes are connected by short, flexible cables, so that the intervening coils on the armature are short-circuited. As the distance between the brushes increases, a larger number of coils will be short-circuited; as these coils lie, however, in the neutral space, the effect of cutting them out is to neutralize their demagnetizing action, thereby increasing the E. M. F. of the dynamo. In order to facilitate adjustment, the brushes are set to a certain length, the amount of their projection from the holders being determined by means of a gauge. The regulator is fastened to one of the yokes *y* of the field. In the larger sizes of these machines, the friction rollers are driven by a light belt from a small pulley on the end of the armature shaft, but otherwise operate in the same manner as that described.

In some of the latest type of Wood machines, the friction wheel *f* and the two friction rollers $f_1$, $f_2$ are replaced by a small, double friction clutch, driven by a belt from the main shaft. In other respects, however, the construction and principle of operation are the same as that described above.

**8. Standard Dynamos.**—These machines have bipolar, consequent-pole, series-wound field magnets. The armature is of the ring type, and differs from that of the Wood machine only in the details of its construction. A single pair of brushes is used, which is shifted to vary the E. M. F. and to keep the current constant by a mechanism situated on the base of the machine. This mechanism is driven by a light belt from a small pulley fastened to the end of the armature shaft.

**9. Western Electric Dynamos.**—In the smaller sizes these machines have bipolar, consequent-pole, series-wound field magnets, with drum-wound armatures; in the larger sizes the field magnets are multipolar, with salient poles, and ring-wound armatures are used.

The machines are regulated to give a constant current by shifting the brushes, as in those previously described; the mechanism for shifting the brushes is driven by a belt from the end of the armature shaft and controlled by a separate controlling magnet, as in the Wood dynamo. The controlling magnet throws into or out of gear or reverses a friction-clutch arrangement, which shifts the brushes forwards or backwards as the load is increased or diminished.

The armature of the Western Electric arc dynamo is toothed, the coils being wound in slots, instead of on the surface. The slots are very carefully insulated because most of these machines generate a very high E. M. F. at full load. The commutator segments are mounted on a marble disk and are arranged so that they may be renewed when they are worn out. Another feature of the machine is that graphite brushes instead of copper are used.

**10. Excelsior Dynamos.**—These machines have bipolar, salient-pole, series-wound field magnets and use ring armatures. An iron arm projects from each pole piece, difference of potential between the brushes fluctuate, so that the current in the external circuit is *pulsating* in character. In speaking of it as a *constant* current, it is meant that the *average* current strength is constant.

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## PRINCIPAL OPEN-COIL CONSTANT-CURRENT DYNAMOS.

**13. Brush Dynamos.**—These machines use a disk-shaped ring-wound armature with projections on both sides of the ring, between which the coils are wound.

The magnetic circuit has four poles, but it is really a consequent-pole, bipolar field magnet, as will be seen from Fig. 3, which represents the field magnet as seen from the top.

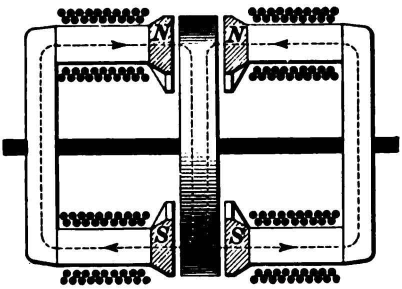

FIG. 3.

The armature winding of these machines consists really of a number of windings, each with a separate commutator. Each winding consists of four coils, arranged in two sets of two coils each. The two coils of each set are placed on opposite sides of the armature core, so that one coil is always in the same position relative to one pole piece that the other coil is to the other pole piece; this being the case, the E. M. F.'s generated in the coils are equal at all parts of their revolution, and they are permanently connected in series, so that they really act as one coil. The other set of coils belonging to the winding is placed on the core in the same manner, but at right angles to the first set, so that when the coils of one set are under the center of the pole pieces, that is, are in their most active position, the coils of the other set are in the neutral spaces, that is, in their least active position.

**14.** It will be seen that this arrangement of the two sets of coils corresponds to the arrangement of the two loops of wire that has been previously described and illustrated. The ends of each of the two sets of coils are connected to two opposite segments of a commutator, as in the previous case, except that instead of each segment being a little less than one-fourth the circumference, so that the brushes leave one pair of segments at the same time that they begin to bear on the other pair, in the Brush commutator each segment covers a little more than one-third the circumference, the segments of one pair being placed alongside the segments of the other pair to allow for this extra length.

This is represented in Fig. 4, *a*, *a'* being the two segments connected to one set of coils, and *b*, *b'* being the two that are connected to the other set. It will be seen from this figure that each of the brushes *1*, *2* rests on one of the two opposite segments *b*, *b'*; but as the commutator revolves, each brush rests on one segment of *each* pair, *a'*, *b'* and *a*, *b*, where they overlap. Consequently, the coils connected to each pair of segments are connected in parallel with each other during a part of each half revolution.

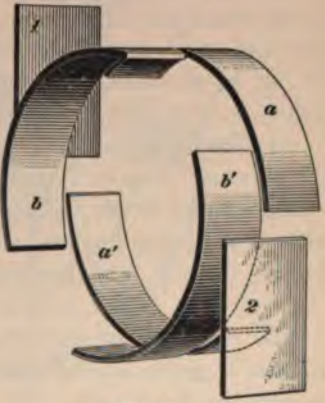

FIG. 4.

If this form of commutator with overlapping segments be connected to two simple loops, it will be seen that at the moment when the two loops of wire are thrown in parallel by each brush resting on two segments, the E. M. F. in the two loops is not the same, that of the loop which had just before alone been connected to the brushes being higher than that of the other. A little later, at the moment when one of the loops is disconnected from the circuit by each brush passing from two segments to a single segment, the coil that is disconnected has a less E. M. F. than the other.

If the loops had little self-induction, this would result in the greater E. M. F. of the one loop sending a current around through the other loop against the E. M. F. generated in it, which current would not appear in the external circuit and would therefore represent so much wasted energy.

This *local current* would evidently be greatest when the difference between the E. M. F.'s of the two coils is greatest, that is, at the moment when the two loops are connected in parallel and at the moment one of the loops is disconnected from the brushes. Then, when the one loop is disconnected from the other, this local current would be suddenly broken, and this would result in sparking.

In the Brush machines, the self-induction of the coils is considerable, so that when two sets of coils are connected in parallel, the self-induction of the coil having the lower E. M. F. prevents this sudden rush of local current and takes up its share of the output of the machine gradually.

At the same time, the parallel connection of the sets of coils is not broken until the E. M. F. of the set that is disconnected is enough lower than that of the other set so that it is furnishing practically none of the current output; hence, there is little sparking when it is disconnected.

**15.** As stated, the Brush armature winding is made up of two or more separate windings, the action of each being as already described.

Fig. 5 represents a Brush armature with two separate windings. In this figure, the pole pieces are represented by the dotted lines as they face the sides of the armature, as shown in Fig. 3. The segments of the two separate commutators are, for convenience, represented as concentric, with the brushes resting on their edges; whereas, actually, they lie side by side, forming two separate commutators of the same diameter, each having four segments, and the brushes rest on their circumferences.

One winding consists of two pairs of coils $A$ $A'$ and $B$ $B'$ located at right angles to each other, the coils of each pair being connected in series, as represented.

This winding is connected to its commutator, coil $A$ to segment *a*, coil *A'* to segment *a'*, coil *B* to segment *b*, and coil *B'* to segment *b'*, as represented. Brushes *1* and *2* rest on this commutator, making contact on the line of maximum action *x y* of the coils. It will be seen that this line is not from center to center of the pole pieces, but is moved ahead (in the direction of rotation, as indicated by the arrows) from this position by the armature reaction.

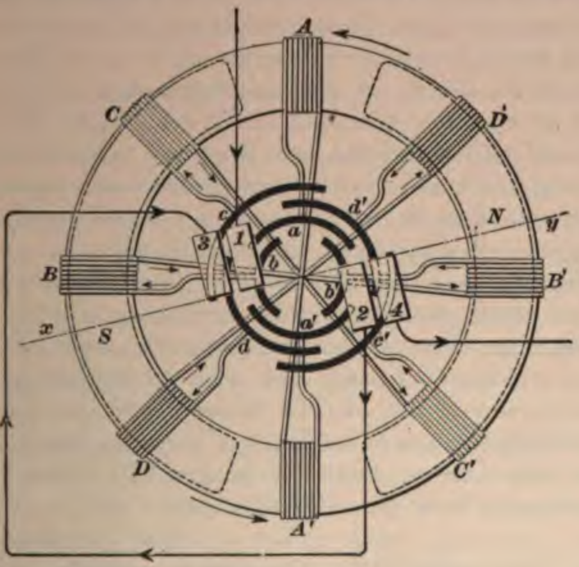

FIG. 5.

The second winding consists of two pairs of coils *C C'* and *D D'*, located at right angles to each other and half way between the coils of the first winding. These coils are connected in series and to the segments of the second commutator, coil *C* to segment *c*, coil *C'* to segment *c'*, coil *D* to segment *d*, and coil *D'* to segment *d'*, as represented. Brushes *3* and *4* rest upon the segments of this commutator on the same line of maximum action of the coils.

Taking each winding separately, it will be seen that its two sets of coils pass through the following combinations: One set of coils only connected to the brushes; then the two sets, connected in parallel and both connected to the brushes; then one set only; then both sets in parallel; and so on.

The maximum E. M. F. occurs when the single set of coils is connected and is directly in the line of maximum action; the minimum occurs one-eighth of a revolution ahead of this point, when both sets of coils are in parallel and are equally distant from the line of maximum action.

This being the case, it is evident that as the coils of one winding are half way between the coils of the other, *the maximum E. M. F. of one winding occurs at the same instant as does the minimum E. M. F. of the other.* On account of this, when the two windings are connected in series, the fluctuations of the current are much reduced.

This connection of the two windings is obtained by connecting, as shown in Fig. 5, the positive brush of one winding with the negative of the other, the external circuit being connected between the two remaining brushes.

In the large sizes of these machines, three and even four separate windings are used, each with its commutator, and all connected in series. In the larger multipolar machines, each winding consists of two sets of coils, each set containing four coils, one for each pole piece. The action is precisely the same as in the bipolar machine.

**16.** The regulation of the Brush machines is nearly automatic; that is, a machine will give *nearly* a constant current without any regulation whatever. This is due to the fact that the armature reaction increases so much with any increase in the current that the line of maximum action is shifted farther ahead, which changes the relations of the various coils at the time when they are connected with, or disconnected from, each other or the external circuit.

This regulation is, however, not close enough for commercial working; so in addition, a resistance is placed in shunt to the magnetizing coils, which is varied by a controlling magnet in the main circuit, thus making the regulation very exact.

This resistance consists of a series of blocks of carbon—a material that has the property of lessening its resistance if subjected to pressure. In this case the pressure is obtained by the pull of the controlling magnet on its keeper, which forms the end of a lever that presses upon the carbon blocks. If the current in the external circuit increases, due to a lessening of the external resistance, the controlling magnet pulls on its keeper with greater force, thus increasing the pressure on the carbons, decreasing their resistance, and weakening the strength of the field magnets, which reduces the E. M. F. of the armature coils until the current is again at its normal strength.

The shifting of the point of maximum action, due to the weakening of the field at light loads, causes a certain amount of sparking, which is remedied by slightly shifting the brushes. In the multipolar machines, this shifting is performed automatically by mechanism driven by a belt from a small pulley on the end of the armature shaft and controlled by the controlling magnet, as in the closed-coil dynamos described.

**17. Westinghouse Dynamos.**—These machines, which are comparatively new, use a multipolar field magnet having six salient poles. The armature coils are wound around eight projecting teeth on the armature core, there being, therefore, eight armature coils. With eight coils and six poles, it is evident that only two coils can be directly under any two pole pieces at the same instant. This armature winding, as in the Brush machine, is divided into two separate windings, each consisting of two pairs of opposite coils and each connected to a separate commutator. The combination of connections of the various sets of coils is similar to that of the Brush machine; that is, the set of coils in the position of least action is disconnected entirely from the circuit, those near the position of maximum action are connected in parallel and in series (by external connection of the brushes) with the set that is actually in the position of maximum action.

In this machine, a coil is in the position of least action when the projection on which it is wound is directly under a pole piece, for when in this position all the lines of force from the pole piece pass directly through the center of the coil, which therefore cuts none of the lines of force. As soon as the coil moves from this position, one side begins to cut the lines of force of the pole piece from which it is moving; then as it moves still farther, the *other* side of the coil begins to cut the lines of force of the pole piece *towards* which it is moving, so that when half way between the two, both sides of the coil are cutting lines of force equally and at the maximum rate, and this is, therefore, the position of *maximum* action.

**18.** A diagram showing the connections of the armature winding to the commutator of the Westinghouse machine is given in Fig. 6. As in Fig. 5, the two commutators are represented as concentric, though they are actually side by side on the shaft, and, as in the Brush machine, are situated on the end of the shaft outside one of the bearings, the leads to the commutator being brought out through a hole in the shaft, instead of being connected directly, as represented in the diagram.

The two pairs of coils *A*, *A'* and *B*, *B'* make up one winding and are connected to one commutator, as represented. The two opposite coils *A*, *A'* and *B*, *B'* are connected in series by connections across the back of the armature core (not shown in the diagram).

The other winding is made up of the two pairs of coils *C* and *C'* and *D* and *D'*, the coils of each pair being connected in series, as before.

It will be seen that each commutator is made up of twelve segments separated by a considerable width of insulating material (indicated by the solid-black parts). These twelve segments are connected by cross-connecting wires, as shown in Fig. 6. The segments that are connected together are one-third a circumference apart, as, for example, segments *d*, *d*, *d*.

Instead of the segments overlapping as they do in the Brush machine, each brush is divided into two parts, which rest on the commutator at a distance apart equal to the length of one segment, as represented at *1 1'* or *2 2'*.

Applying the statement made in the last article to Fig. 6, it will be seen that coils *A* and *A'* are in the position of least action and are disconnected from the external circuit. The other set of coils of this winding, *B* and *B'*, is, however, in the position of maximum action and is connected to the circuit through brushes *1* and *1'* and *2* and *2'*, which rest on segments *b*, *b'*, respectively. Of the second winding, each set of coils *C*, *C'* and *D*, *D'* is equally distant from the position of maximum action, and these two sets are therefore connected in parallel with each other through brushes *4*, *4'*, which rests on segments *c*, *d*, and brushes *3*, *3'*, which rest on segments *c'*, *d'*, and are connected in series with the

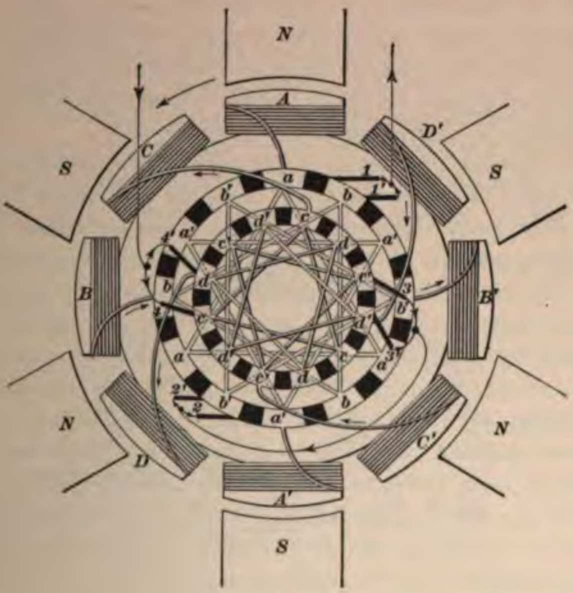

FIG. 6.

set of coils *B*, *B'* by the external connection between the two sets of brushes *2*, *2'* and *3*, *3'*.

To follow out the changes in the connections of the coils, consider that the armature is moving in the direction indicated by the arrow. As coils *B*, *B'* move from their position of maximum action, brushes *1'*, *2'* are disconnected from segments *b*, *b'*, and as the armature moves, finally come into contact with segments *a'*, *a*, thus throwing the two sets of coils *A*, *A'* and *B*, *B'* in parallel. At the same time, brushes *4* and *3* being disconnected by the insulating segment from segments *c*, *c'*, coils *D*, *D'* only of the second winding are connected to the circuit through brush *4'* and in series with the coils of the other winding (now connected in parallel) through brush *3'* and its connection with brushes *2*, *2'*, coils *C*, *C'* being entirely disconnected.

It will be seen that these successive combinations of coils are precisely the same as take place in the Brush machine, except that each combination takes place six times in each revolution, instead of twice, which is due to the multipolar field. The regulation of this machine is entirely automatic. The field magnets are separately excited, the current being furnished by a separate constant-potential dynamo, which gives a constant magnetizing force; but the strength and distribution of the resulting field are dependent on the armature reaction, which is so proportioned that any excess of current over the normal so reduces and distorts the field that the E. M. F. generated in a winding during the time that it is connected to the brushes is reduced until the current is again at its normal strength.

**19. Thomson-Houston Dynamos.**—These machines have bipolar, series-wound, salient-pole field magnets. The completed armature is nearly spherical in shape and the pole pieces are bored out accordingly, so that they almost entirely enclose the armature.

In the older machines, the armature is drum-wound, although the core is a ring, but in the newer machines, a ring winding is used; in either case, three separate coils, or sets of coils, make up the winding. One end of each of these coils (or sets of coils) is connected to a commutator segment, all the other ends being joined together.

The commutator has three segments, each covering nearly one-third the circumference, the balance being made up by the air spaces that separate the segments.

Two positive and two negative brushes are used, those of each pair resting on the commutator at two points at a distance apart equal to one-half a commutator segment, that is, nearly one-sixth the circumference, when the machine is giving its greatest E. M. F.

**20.** A diagram of the connections, etc. of the drum-wound armature is shown in Fig. 7. *A A'*, *B B'*, and *C C'* are the three coils wound on the core one-third the circumference apart. One end of each of the coils is joined to a metal ring (not represented in the figure) on the back of the armature, which forms a common connection for the three.

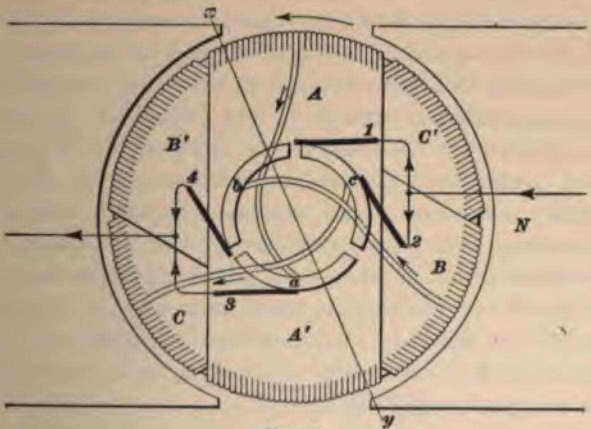

FIG. 7.

The other ends are joined to the commutator segments, that of *A A'* to segment *a*, that of *B B'* to segment *b*, and that of *C C'* to segment *c*, as represented; *1* and *2* are the negative, and *3* and *4* the positive, brushes. Brushes *2* and *4* are usually called the *primary* brushes and *1* and *3* the *secondary* brushes, to distinguish them.

From the diagram, Fig. 7, it will be seen that coil $A A'$, though half way between the pole pieces, is partly active, since the neutral line is shifted forwards by armature reaction, as indicated by the line $x y$. This coil $A A'$ is connected in parallel with coil $B B'$ by the two positive brushes, and the two are in series with coil $C C'$. If the armature be considered as moving in the direction indicated by the arrow, it will be seen that as coil $A A'$ gets to the position of least action, it is disconnected from the circuit by segment *a* passing from under brush *3*, leaving coil $B B'$ and coil $C C'$ in series. However, as the distance between brush *3* and brush *2* is only slightly greater than the span of one segment, coil $A A'$ is almost immediately connected in parallel with coil $C C'$, as segment *a* passes under brush *2*, making the following combination: Coil $B B'$ in series with coils $A A'$ and $C C'$ in parallel.

As the rotation of the armature continues, coil $C C'$ is disconnected from the negative brush *1* and connected to the positive brush *4*, being thus thrown in parallel with coil $B B'$, the two being then in series with coil $A A'$.

Completing the half revolution, coil $B B'$ is disconnected from the positive brush *3* and is joined in parallel with coil $A A'$ by the two negative brushes *1* and *2*, leaving coil $C C'$ connected to the positive brushes.

Further rotation of the armature repeats this series of connections; that is, during every half revolution, one of the coils ($A A'$ in the preceding paragraphs) is first in parallel with the coil *behind* it, then momentarily disconnected from the circuit, then connected in parallel with the coil *ahead* of it, then connected in series with the other two, which are then in parallel.

From the diagram, Fig. 7, it will be seen that when a coil is disconnected from one set of brushes, it is very nearly in the position of least action, and the coil with which it was just before connected in parallel has the higher E. M. F. of the two. As has been explained, the self-induction of the coil prevents the higher E. M. F. of the other sending a current through it in opposition to its own E. M. F. at the time when they are connected in parallel; in fact, when the coil is disconnected from its mate, it is still supplying some of the current, so that there is a spark at the brushes.

**21.** The regulation of this machine is effected by varying the distance between the two brushes of each set, the primary brush being moved back and the secondary ahead. This movement of the brushes decreases the distance between the primary brush of one set and the secondary of the other. Now, as when in the position shown in Fig. 7, this distance is only slightly greater then the span of one commutator segment, it is evident that lessening this distance will allow of one segment being under *both* one of the positive and one of the negative brushes during a part of a revolution, which *short-circuits* the armature, reducing the difference of potential between the brushes (momentarily) to zero.

As the field magnets are in series with the armature, their great self-induction prevents the strength of the current falling to zero, its fluctuations being comparatively small. At the same time, the self-induction of the armature coils prevents any excessive flow of current from one to the other through this short circuit; for, there being two places where the short circuit occurs, i. e., between brushes *1* and *4* and *2* and *3*, and there being three commutator segments, it is evident that six short circuits occur during every revolution, and if the armature is revolving at 850 revolutions per minute, there are $6 \times 850 = 5,100$ short circuits every minute, so that each lasts only an extremely short time.

As the distance between the brushes of a set is increased, each short circuit is kept up for a slightly longer time. It will be seen that this momentary reduction of the difference of potential between the brushes to zero reduces its effect in sending a current through the circuit, although its maximum value is not much reduced; so that by shifting the brushes at the proper time, the current in the external circuit can be kept at a constant strength, in spite of variations in the external resistance.

This shifting of the brushes is done automatically by the following apparatus: The primary and secondary brushes are mounted on separate rocker-arms, which are connected together by a system of levers, so that when the primary brushes are shifted back, the secondary are moved ahead. The amount of movement of the secondary brushes is very little, being for the purpose of following the line of maximum action, which moves ahead slightly at light loads (low E. M. F.). A large magnet attached to the frame of the machine has attached to its keeper a lever, which is connected to the rocker-arm that carries the primary brushes, so that when the keeper of the magnet is pulled up, the primary brushes are shifted back and the secondary ahead, thus reducing the effective difference of potential between the brushes, as explained. The current for operating this regulating magnet is supplied by the main current, but it is not continually in circuit, being cut in or out, as occasion requires, by a controlling magnet that is placed on the wall of the room at some convenient place.

**22.** Fig. 8 is a diagram of the connections used in this apparatus. $R$ represents the regulating magnet and $K$ its keeper, which is connected to the rocker-arms by a lever (not shown), as described. $C$, $C$ represent the coils of the controlling magnet, which are stationary, and $D$, $D$ represent the cores of this magnet, which are movable. Their weight is partly counterbalanced by the spring $s$, the tension of which is adjusted by means of the nuts at $N$. Attached to these cores is a contact point, which touches a stationary contact piece at $B$. The connections being as represented, + being the positive terminal of the dynamo, it is evident that when the two contact points at $B$ are touching, the regulating magnet $R$ is short-circuited, the current flowing from + to $p^2$, thence to $P^2$, thence through the contact points at $B$ to $P$, thence through coils $C$, $C$ to $P^1$, and out to the line. Now, if this current exceeds a certain strength, the pull of the coils $C$, $C$ on the cores $D$, $D$ becomes sufficient to raise them, breaking the contact at $B$. This forces the current around from $P^2$ through the regulating magnet $R$ to $P$, thence to $P^1$, where it passes out to the line as before. The regulating magnet then attracts and pulls up its keeper $K$, which in moving shifts the brushes and reduces the current as described.

When the current is reduced to its normal value, the cores of the controlling magnet descend, and contact is made at $B$, which short-circuits the regulating magnet and allows its keeper to drop. This shifts the brushes again so as to increase the current. This action is kept up, so that the cores of the controlling magnet and the brushes of the machine are continually in slight motion. In order to prevent the self-induction of the regulating magnet causing a serious spark at $B$ when the contact is broken, a shunt of high resistance is permanently connected around the break at $B$, as represented at $r$. An induced E. M. F. is set up in the regulating magnet $R$ whenever the circuit is opened at $B$, for this suddenly diverts the main current through the regulating magnet, whose momentary self-induction opposes the current, forcing it along by way of $p^2$, $P^2$, and the resistance $r$ to the line. If the resistance were not there, the current would cross the air gap at $B$, making a destructive spark.

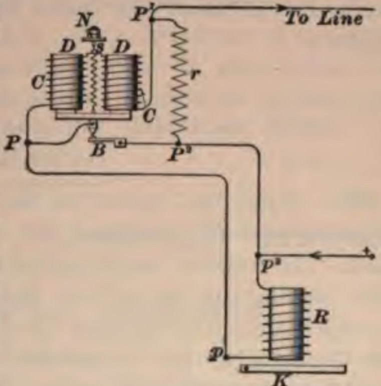

FIG. 8.

The space between the ends of the commutator segments being small, some device is necessary to prevent the spark that occurs when a segment passes from under one of the secondary brushes continuing to pass from segment to segment, for that would permanently short-circuit the machine. This device consists of a small rotary blower, which is situated between the commutator and the bearing. This

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blower is so arranged as to deliver a puff of air right at the end of the secondary brushes at the moment that the spark occurs, so that it is immediately broken and does no damage.

The adjustment of the commutator, brushes, air blast, etc. of this machine requires considerable attention in order that the machine should run well. The manufacturers supply printed matter with each machine, giving full particulars of these operations, hence they need not be taken up here.

## THE OUTPUT OF CONSTANT-CURRENT DYNAMOS.

**23.** From the nature of the output, the heat losses in constant-current dynamos are practically constant at all loads. In some of the open-coil machines, the local currents that circulate in the coils at light loads may be of greater strength than the current in the external circuit, so that the heating of the armature may be even greater at light loads than at full load. It is evident, however, that the heating is not the factor that limits the load, nor is the sparking, since the machine must be so designed that the sparking is the same at all loads. The factor of the load that varies is the E. M. F., so that when this has reached its highest value, any further increase in the external resistance can only reduce the current, since the E. M. F. cannot increase farther. The maximum E. M. F. that the machine can give determines then the limit of its output.

Constant-current machines may be rated according to their output, expressed in kilowatts (1 kilowatt being 1,000 watts), as are constant-potential machines; but as they are almost invariably used for operating *arc lamps*, they are usually rated according to the maximum number of lamps for which they can supply current. The strength of the current most used is from 9.5 to 10 amperes, 9.6 being the standard adopted by many manufacturers. With this current, each arc lamp requires from 45 to 50 volts. All lamps being connected in series, this makes the maximum E. M. F.

of, for example, an 80-light dynamo 80 × 50 = 4,000 volts. Machines are built of 150 lights capacity, but the sizes most generally used have a capacity of from 50 to 80 lights. When enclosed arc lamps are used a current of 6.6 amperes is common, the voltage per lamp being from 70 to 80 volts.

Almost all the regulating devices used are practically independent of the speed, so that they will maintain the current constant when the speed varies somewhat, if the variations are not too sudden. Any reduction in the speed, however, reduces the maximum E. M. F. and output that can be obtained, and, conversely, an increase in the speed will increase the possible output.

## DIRECT-CURRENT ELECTRIC MOTORS.

### PRINCIPLES OF OPERATION.

**24.** Electric motors designed to be operated by continuous current were in use before the dynamo was invented. Such motors were operated by batteries, and usually were made up by arranging pieces of iron so that they would be successively attracted by electromagnets, and thus give rise to motion. Several styles of such motors were made, and although they operated after a fashion, they ultimately proved failures, and attempts to utilize electricity as a source of mechanical energy by this means proved fruitless. The cause of this failure was twofold. In the first place, batteries proved to be a very expensive means of generating the current necessary, and, secondly, motors built on the lines indicated above were very inefficient, delivering only a very small amount of power at the pulley compared with the amount of power supplied to them. The invention of the dynamo afforded a cheap and convenient means of generating current, so that after its invention attention was again given to electric motors. Soon after the invention of the dynamo, it was found that the same machine that operated as a dynamo could also be run as a motor if it were fed with current from an outside circuit; in other words, that the ordinary continuous-current dynamo was reversible in its action. It was also found that an electric motor designed on the same lines as the dynamo would convert electrical energy into mechanical energy quite as efficiently as the dynamo would perform the reverse operation. Direct-current motors came into rapid use for transmitting power, and although the alternating-current motor is beginning to take their place in some cases, there are still large numbers of them used. The most extended use of direct-current motors at present is probably in connection with street railways, the alternating current having been used very little for this purpose as yet.

## DYNAMOS AND MOTORS COMPARED.

**25.** A dynamo may be defined as a machine for the generation of an electromotive force and current by the motion of conductors through a magnetic field. This motion and the force necessary to maintain it must be supplied by a steam engine or other source of power. On the other hand, a motor may be defined as a machine for supplying mechanical power when supplied with an electric current from some outside source. The motion and the force necessary to maintain it is, in this case, supplied by the reaction between the current flowing in a set of conductors and the magnetic field in which the conductors are placed.

**26.** As far as the electrical features of a continuous-current motor are concerned, they are almost identical with those of the continuous-current dynamo. The differences in the two that occur in practice are very largely differences in mechanical details that are necessary to adapt the motor to the special work that it must do. This is notably the case with street-railway motors, motors used in mining and hoisting work, etc. The class of work that such motors have to perform renders it necessary that they should be enclosed as much as possible. No matter what may be the mechanical design of such motors, they all consist of the same essential parts as the dynamo, namely, field magnet, and armature with its commutator, brush holders, etc.

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## ACTION OF MOTOR.

**27.** It is necessary to consider carefully the forces acting in a motor, in order to understand clearly the behavior of different kinds of motors when operated under given conditions. In order to do this, we will consider the force acting on a conductor that is carrying a current across a magnetic field. Suppose the arrows, Fig. 9, represent magnetic lines of force flowing between the pole faces of the magnet *N S*, and let *a* represent the cross-section of a wire lying at right angles to the lines. So long as no current flows through the wire, the field will not be distorted, and there will be no tendency for the wire to move. If the ends of the wire are connected to a battery so that a current flows, say, down through the paper, this current will tend to set up lines of force around the wire, as shown by the dotted circles in Fig. 10. It will be noticed that these lines tend to oppose

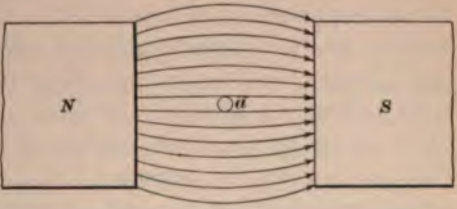

FIG. 9.

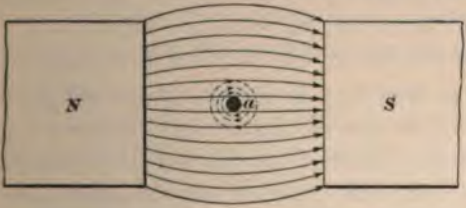

FIG. 10.

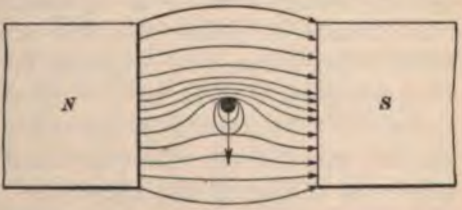

FIG. 11.

the original field below the wire and make it more dense above the wire. The resultant effect is that the field is distorted, as shown in Fig. 11, and the lines of force from $N$ to $S$ that tend to straighten themselves out force the wire downwards.

**28.** The action described in the simple case just given is essentially that which takes place in an electric motor. The magnetic field is supplied by the field magnet, which is excited by means of current taken from the mains to which the motor is connected. Current from the line is led into the armature windings by means of the commutator and brushes, and this armature current reacts on the field, thus driving the armature around. The commutator keeps the relation between the current in the conductors and the field such that the twisting force, or *torque*, acting on the armature is continuous, and a uniform rotary motion is the result. The effort exerted by the reaction between the field and the current in each individual conductor may be quite small; but it must be remembered that the armature is usually provided with a large number of conductors, so that the total resulting torque may be quite large.

**29.** By referring to Fig. 11, it will be seen that in a motor the conductors are *forced* across the field by the reaction of the armature current on the field. That is, *the force exerted by the magnetic field on the armature conductors of a motor is in the same direction as the motion of the armature.* This force is used for doing mechanical work. Compare this with the action of a dynamo. The dynamo armature is driven by means of a steam engine or other source of power, and the armature conductors are made to cut across the magnetic field, this motion causing the generation of an E. M. F. When the outside circuit is closed, so that current flows through the armature conductors, this current reacts on the field in such a way as to *oppose* the motion of the armature. The more current the dynamo supplies, the greater is this opposing torque action between armature and field and the more work must the steam engine do to keep the dynamo operating. In the case of a motor, the greater the load applied to the pulley, the greater must be the torque action between the armature and field to keep up the motion, and the greater the amount of current that must be supplied from the line. It is thus seen that as regards the torque action between the armature and field, the motor is just the opposite of the dynamo, the force action in the former case being *with* the direction of motion and in the latter case *against* it.

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### COUNTER E. M. F. OF MOTOR.

**30.** It was shown, in connection with the study of the theory of the dynamo, that whenever a conductor is moved in a magnetic field so as to cut lines of force, an E. M. F. is induced in the conductor. In the case of a dynamo, an E. M. F. is generated in this way, and this E. M. F. is made use of to set up currents in outside circuits. In other words, the E. M. F. is the *cause* of the flow of current, and consequently the E. M. F. is in the same direction as the current.

In a motor we have all the conditions necessary for the generation of an E. M. F. in the armature; that is, we have an armature revolving in a magnetic field and conductors cutting across lines of force. It is true that, in the case of a motor, the armature is not driven by a belt as in the case of a dynamo, but is driven around by the force action between the field and armature. This, however, makes no difference as far as the generation of an E. M. F. is concerned.

When a motor is in operation, there must be an E. M. F. generated in its armature, and for the present we will term it the **motor E. M. F.** Take the simple case shown in Fig. 11—as the conductor is forced down, it will pass across the magnetic field and an E. M. F. will be induced in it. Also, by applying the rule for determining the direction of the induced E. M. F., we see that it must be directed upwards, that is, towards us along the conductor (the direction of motion being down and the direction of the field from left to right). The *current* flowing in the conductor is flowing from us, or is being opposed by the motor E. M. F. We may state, then:

*In an electric motor, the E. M. F. generated in the armature is opposed to the current that is flowing through the armature.* Owing to the fact that the motor E. M. F. is opposed to the current, it is commonly spoken of as the **counter E. M. F.** of the motor. It is important that the student should clearly understand the generation of this counter E. M. F. and its relation to the current. As regards the generation of E. M. F., the motor is the opposite of the dynamo, as in the latter case the E. M. F. is always in the same direction as the current.

**31.** In order that a current may be sent through the armature of a motor, the E. M. F. of the dynamo supplying the current must be greater than that of the motor. Suppose a dynamo $A$, Fig. 12, is supplying current to the motor $B$. Let $E$ be the E. M. F. maintained between the mains by the dynamo $A$. We will suppose $E$ to be kept constant independent of the current delivered. The motor when running will generate a certain counter E. M. F. which we will call $E_m$. Part of the line pressure will be used in overcoming the counter E. M. F. $E_m$ of the motor and the remainder in overcoming the resistance of the armature. If $C$ is the current flowing through the armature, we must have the relation

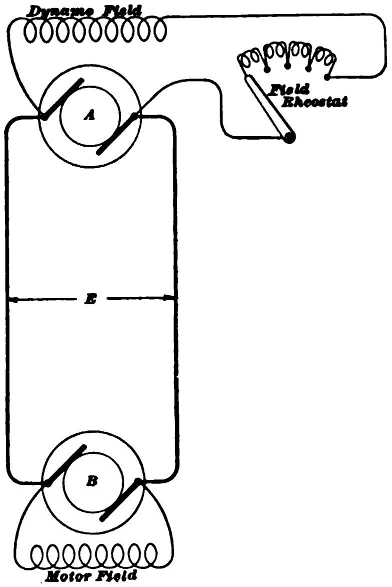

FIG. 12.

$$E = E_m + C R_a, \qquad (1.)$$

where $R_a$ is the resistance of the armature. This must hold true for any value of the current. If the field coil were connected in series with the armature instead of in shunt as shown, a small part of $E$ would also be required to overcome the resistance of the field winding.

**32.** It is evident from formula **1** that if the current flowing is very small (which is the case if the load on the motor is very light), the counter E. M. F. $E_m$ is nearly equal to the E. M. F. $E$ maintained between the lines by the dynamo. If $E$ and $E_m$ were exactly equal, no current would flow in the circuit. In practice, $E_m$ never becomes quite equal to $E$, because it always takes a small amount of current to run a motor even if no load is applied to the pulley. There is always, therefore, a slight amount of the line pressure taken up in overcoming the armature resistance, and $E_m$ is always less than $E$, as shown by formula **1.**

Since the counter E. M. F. is nearly equal to the applied E. M. F., it is only necessary for it to vary a small amount to vary the current within wide limits. For example, if the resistance of a certain armature is 1 ohm and it is supplied with current at a constant potential of 250 volts, then, when a current of 10 amperes is flowing through it, the drop is $10 \times 1 = 10$ volts, and the counter E. M. F. is $250 - 10 = 240$ volts. Now, if the current is reduced to 1 ampere, the drop is $1 \times 1 = 1$ volt, and the counter E. M. F. is $250 - 1 = 249$ volts; that is, the counter E. M. F. varies only $\frac{9}{240}$, or 3.75 per cent., while the current varies $\frac{9}{10}$, or 90 per cent.

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### TORQUE.

**33.** As already stated, the reaction between the currents in the armature conductors and the magnetic field produces a twisting action which is called the **torque.** This torque may be present whether the motor is running or not because, even if the armature is held from turning, it is evident that a strong twisting effort or tendency to turn may still be exerted.

The amount of the torque—which is usually expressed in **pound-feet,** that is, a certain number of pounds acting at a radius of a certain number (usually 1) of feet—depends on (1) the strength of the field; (2) the number of conductors; (3) their mean distance from the axis of the armature; and (4) the amperes in each conductor. In any given machine, the second and third conditions are constant, so that the torque depends on the strength of the field and the current.

**34.** The torque of a motor is equal to the number of *pounds pull* exerted at the circumference of the pulley or at the pitch circle of the gear multiplied by the radius of the pitch circle of the pulley or gear. This torque is the same for a given current, whatever may be the speed. But for each revolution of the motor, the point at which the pull is exerted moves through a certain distance (that is, once around the circumference of a circle) equal to 3.1416 times the diameter of the circle, or to 2 × 3.1416 × the radius of the circle, at the circumference of which the pull is considered to act.

Each revolution of the motor, then, when a certain torque is exerted, corresponds to a certain number of *foot-pounds of work done*.

This number of foot-pounds will be the same for a given torque, whatever may be the radius of the circle through which the point of application of the pull moves; for, if a radius be taken that is twice as long as another, the distance moved through will be twice as great, but the pull in pounds that the motor is capable of exerting at twice the former radius will be only half as much, so that their product remains the same. For the sake of uniformity, a standard radius of 1 foot is used, and the torque is expressed in *pounds at 1 foot radius*.

It will be noticed that the words *moment* and *torque* have the same meaning.

The foot-pounds of work done in each revolution and the number of revolutions per minute being known, the foot-pounds of work done per minute, and from that the horsepower, may be found by the following formula:

$$\text{H. P.} = \frac{2 \times 3.1416\, T S}{33{,}000} = .0001904\, T S, \qquad \textbf{(2.)}$$

in which $T$ represents the pull in pounds at 1 foot radius, that is, the torque; $S$ the number of revolutions per minute; and H. P. the horsepower.

Hence, *to obtain the horsepower of a motor, multiply 3.1416 by 2, this product by the torque (expressed in pounds at 1 foot radius), and this product by the number of revolutions per minute; divide the final product by 33,000.* An alternative method is to use the constant .0001904, and multiply this by the product of the torque and speed expressed as above.

If the H. P. and the torque are known, the number of revolutions per minute may be found from a modification of the above formula:

$$S = \frac{33{,}000 \text{ H. P.}}{2 \times 3.1416\, T} = \frac{\text{H. P.}}{.0001904\, T}. \qquad \textbf{(3.)}$$

Or, if the H. P. and the number of revolutions per minute are known, the torque may be found from the formula

$$T = \frac{33{,}000 \text{ H. P.}}{2 \times 3.1416\, S} = \frac{\text{H. P.}}{.0001904\, S}. \qquad \textbf{(4.)}$$

**35.** Fig. 13 illustrates a method of measuring the torque of a motor by means of a **Prony brake.**

This brake consists of two blocks of wood $B$, $B$ made to fit the surface of the pulley $P$. These two blocks bear on the pulley on opposite sides, as represented, and their pressure on the pulley is regulated by means of the thumb-nuts $N$, $N$ on the bolts that hold the two parts of the brake together.

The lower of the two blocks of wood is extended in both directions, forming on the one side an arm $A$ that presses on the platform of a set of scales $S$, and on the other a place where weights $W$ may be placed to balance the weight of the arm *A*. A spike, or lagscrew, *C* should be driven through the end of the arm *A* to better locate the point where it presses on the scale platform.

If the pulley *P* is revolved in the direction indicated by the arrow, the friction of the brake will cause it to tend to rotate with the pulley, which will cause the spike in the end of the arm *A* to press down on the scale platform, and the amount of this pressure may be weighed by the scale beam. The *product* of the number of pounds pressure and the *horizontal* distance *R* between the point *C* and the center of the pulley in feet, will give the torque in *pound-feet*. Then, if the number of revolutions per minute of the motor is counted, the horsepower absorbed by the friction of the brake, that is, the output of the motor, may be calculated by formula **2.** If at the same time the amperes input and the voltage at the motor terminals are measured, their product will be the watts input, and by reducing the output and the input to the same units, the efficiency may be calculated by dividing the output by the input.

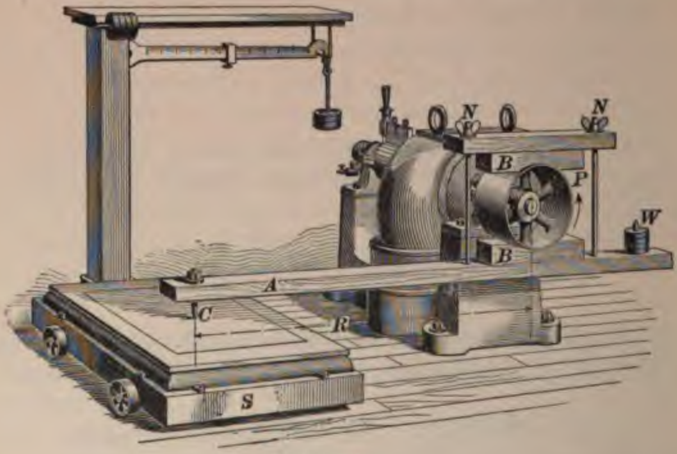

FIG. 13.

**36.** The following example shows the application of the above rules and method of testing motors:

EXAMPLE.—A given shunt-wound motor is designed for an output of 10 H. P. and to be run on a constant-potential circuit of 230 volts. When driving a certain piece of machinery, it requires an input (to both field and armature) of 35 amperes at 230 volts. It is desired to find the actual horsepower required to drive this machinery. The motor is disconnected from its load and a Prony brake rigged up as shown in Fig. 13. The thumbnuts are screwed up until an ammeter in the motor circuit indicates that 35 amperes are flowing through the motor circuit, and the voltage at the terminals is found to be 230 volts. Under these conditions, the pressure on the scale platform is found to be 24 pounds and the speed of the motor 800 revolutions per minute. The horizontal distance between the center of the shaft and the point where the brake arm rests on the scales is 30 inches. What is the output of the motor at this load in horsepower, and what is its efficiency?

SOLUTION.—The distance $R$, Fig. 13, being 30 inches, or $2\frac{1}{2}$ feet, and the pressure on the scales being 24 pounds, the torque of the motor is $24 \times 2\frac{1}{2} = 60$ pound-feet. Substituting this value for $T$, and 800 for $S$, in formula **2**, gives

$$\text{H. P.} = \frac{2 \times 3.1416 \times 60 \times 800}{33,000} = \frac{301,593.6}{33,000}.$$

NOTE.—As the instruments used are liable to slight errors, four figures (other than the zeros) left in the calculations will be near enough; if the last figure dropped is equal to 5 or more, the last figure *kept* should be increased 1.

Then, $\frac{301,600}{33,000} = 9.1393$, or 9.139 H. P. is the output of the motor. Ans.

The input is $35 \times 230 = 8,050$ watts. Reducing 9.139 H. P. to watts gives $9.139 \times 746 = 6,817.694$, or 6,818 watts. Then, the efficiency

$$\mathsf{E} = \frac{6,818 \times 100}{8,050} = 84.7 \text{ per cent.} \quad \text{Ans.}$$

**37.** The loss represented by the difference between the input and the output is made up of exactly the same elements as the total loss in dynamos; that is, mechanical friction, core loss, field loss, and armature loss. As in dynamos, the armature loss and field loss may be calculated from the resistance of the armature and field coils, remembering that in a shunt motor the *armature* current is *less* than the *total* current, since the field circuit is in parallel with the armature. The core loss and friction taken together evidently equal the difference between the total loss and the sum of the armature and field losses; they cannot be separated without special tests being made.

In a shunt motor, the field loss, core loss, and friction are all practically constant at all loads, since the speed is nearly constant. This being the case, the *watts required to run the motor without any external load whatever* is a measure of these losses plus a certain small amount of armature $C^2 R$, which may be calculated, though it is usually small enough to be neglected without much error. This being the case, the output which a motor will give at any given input will be very closely equal to that input less the watts required to run the motor free, and also less the armature $C^2 R$ loss at the given input; from this the efficiency may also be calculated. To determine the efficiency of the motor at any load within its rated capacity, then, it is only necessary to carefully measure its input at no load (running *light* or *free*), and to make the above calculation. This, however, will give no idea of its performance as to heating and sparking, under the calculated load, so that the Prony-brake test is more satisfactory.

For example, a certain shunt-wound motor requires a current of 1.2 amperes at 500 volts when running *free*, i. e., without external load. Its armature resistance is 2.4 ohms and its field resistance is 834 ohms. Its field current is then $\frac{500}{834} = .5995$ ampere, or, say, .6 ampere. Its armature current is then $1.2 - .6 = .6$ ampere, and its armature loss only $.6 \times .6 \times 2.4 = .864$ watt, which may be neglected.

The input amounts to $1.2 \times 500 = 600$ watts, of which the field loss is $.6 \times 500 = 300$ watts.

If the efficiency when taking 10 amperes at 500 volts is wanted, it may be found from the above figures, as follows: Total input, $10 \times 500 = 5{,}000$ watts. Field loss and core loss and friction combined amount to 600 watts, as found above. The armature loss amounts to $9.4 \times 9.4 \times 2.4 = 212.06$, or, say, 212 watts. The total loss is then $600 + 212 = 812$ watts, so that the output is $5{,}000 - 812 = 4{,}188$ watts and the efficiency $(E) = \frac{4188}{5000} = .837$, or 83.7 per cent. In a similar manner the efficiency at any other input, or the input required for any given output, may be found.

The input, and consequently the output, of constant-potential motors is limited by the same factors that limit the output of dynamos, namely, heating and sparking.

In motors, as the direction of the current for the same direction of the lines of force of the field and of rotation is *opposite* to that in a dynamo, the armature reaction shifts the neutral space in the opposite direction, that is, *backwards*, *against* the direction of rotation. Consequently the brushes of a motor must be shifted *backwards* as the load increases.

## CLASSES OF MOTORS.

**38.** Continuous-current motors, like dynamos, are generally classed according to the methods adopted for exciting the field magnets. This naturally divides continuous-current motors into the following classes:

(1) Shunt-wound; (2) series-wound; (3) compound, or differentially and accumulatively, wound.

Motors may also be operated with separately excited fields, but this is seldom done in practice. By far the larger part of the motors in use belong to the first two classes, the third class being used only to a limited extent. Differentially wound motors are used in some cases where very close speed regulation is required, and motors with a combination of series and shunt windings are used to some extent for the operation of electric vehicles. Nearly all motors are operated on *constant-potential* circuits, the voltage across the terminals being maintained constant or nearly so by the dynamo supplying the system and the current taken by the motor varying with the load. In a few cases motors are operated on *constant-current* arc-light circuits, but their use is very limited. In this case the current through the motor remains constant, and the voltage across its terminals increases with the load.

Shunt motors are used to drive machinery that requires a nearly constant speed with varying loads or that would be damaged if the speed should become excessive, such as ordinary machinery in shops and factories, pumps, etc. Series-wound motors are used on street cars, to operate hoists, etc., where the torque required at starting and getting quickly up to speed is much greater than the normal amount and where large variations in speed are desired.

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### SHUNT-WOUND MOTORS.

**39.** Outside of railway work, the shunt motor is more largely used than any other type because of the valuable speed-regulating qualities that render it well adapted for the operation of all kinds of machinery. The shunt-wound motor is identical, so far as its electrical construction is concerned, with the shunt-wound dynamo. These motors are operated on constant-potential systems, the motor being connected directly across the mains when running, as shown in Fig. 14, where *A* is the armature and *F* is the field. If *E*, the E. M. F. between the mains, is maintained constant, the current flowing through the shunt field will be constant. The field coils will, therefore, supply the same magnetizing force, no matter what current the armature may be taking from the mains. The strength of field would be practically constant if there were no demagnetizing action of the armature. Take the case where the motor is running free and the only load that the armature currents have to overcome is the friction and other losses within the armature. The amount of energy that the motor will take from the line will just be sufficient to counterbalance these losses, and the armature will run up to a speed such that the counter E. M. F. will allow just sufficient current to flow to supply this loss of energy. Since this current is very small in a good motor, the counter E. M. F. when the motor is running light is very nearly equal to the line E. M. F. *E*.

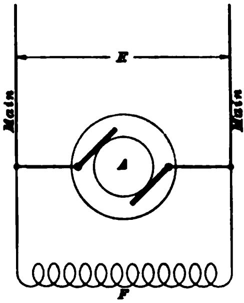

FIG. 14.

**40. Action of Shunt Motor.**—When a load is applied, the motor must take sufficient current to enable the armature to produce a torque sufficient to carry the load. In order to allow this current to flow, the counter E. M. F. must be lowered slightly, and as the field is nearly constant, this means a slight lowering of speed, because the counter E. M. F. $E_m$ for a two-pole motor is given by the expression

$$E_m = \frac{2\,N\,S\,n}{10^8},$$

where $N$ is the total number of lines of force threading the armature, $S$ the number of conductors in series between the brushes, and $n$ the speed in revolutions per second. $S$ and $N$ are practically fixed. At the same time it must be remembered that the armature reaction will make $N$ slightly less when the motor is loaded than when it is not loaded, and this weakening of the field tends to keep up the speed. The net result is, therefore, that a shunt-wound motor operated on a constant-potential circuit falls off slightly in speed as the load is applied, but if the motor is well designed and has a low-resistance armature, the falling off in speed from no load to full load will be very small. It is this speed-regulating feature that makes the shunt-wound motor so widely used. If the load should be accidentally thrown off, there is no tendency to race, and the motor automatically adjusts itself to changes in load without materially changing its speed and without the aid of any mechanical regulating devices.

**41. Speed Regulation.**—The speed of a shunt-wound motor fed from constant-potential mains may be varied either by cutting down the applied E. M. F. $E$ or by changing the field strength. For any given load the motor has to generate a certain counter E. M. F.

$$E_m = \frac{2\,N\,S\,n}{10^8}$$

Solving this for $n$, we have

$$n = \frac{E_m\,10^8}{2\,N\,S}. \qquad \textbf{(5.)}$$

It follows from formula **5** that if the field strength $N$ be decreased, the speed $n$ will be increased, the line E. M. F. remaining the same; also, if the field be strengthened, the speed will be decreased. This simply means that with a strong field the motor does not have to run as fast to generate a given counter E. M. F. as it would if the field were weak. The method of regulating the speed of a shunt-wound motor by varying its field strength is sometimes used. It is the most efficient method for regulating speed, as it only necessitates cutting down the small field current by means of a resistance. The method described in the next article is, however, more generally used, though it causes a much larger waste of energy. In using the field method of control, care must be taken to see that the weakest field used will allow the machine to operate without sparking.

**42.** The speed may also be regulated by leaving the field at its full strength and cutting down the voltage applied to the armature by inserting an adjustable resistance in series with it. The connections for this method of speed regulation are shown in Fig. 15, the adjustable rheostat $R$ being connected in series with the armature $A$ and the field $F$ connected directly across the mains. This method is

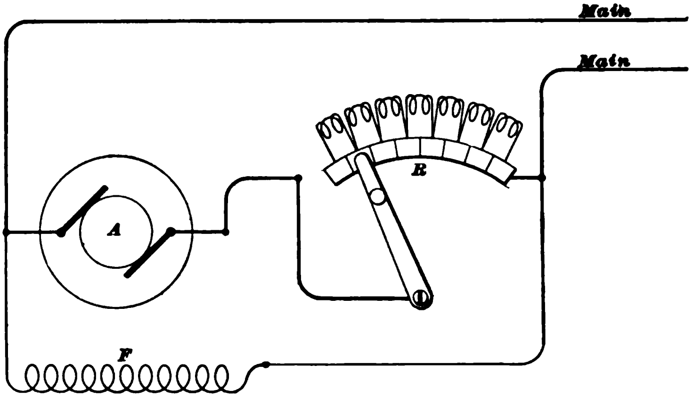

FIG. 15.

rather wasteful of energy, but it is the one generally used when it is desired to control the speed of a shunt-wound machine. If a shunt-wound motor be overloaded or stalled in any way, the current becomes excessive, and the armature is burned out, unless it is protected by fuses (pieces of soft fusible metal that melt when the current becomes excessive) or other safety device. Care should also be taken never to open the field circuit of such a machine while its armature is connected to the circuit. If the field circuit is opened, the machine is unable to generate any counter E. M. F., and the consequence is a large rush of current through the armature, which is at least apt to burn the commutator, and if not interrupted by means of fuses will in a short time burn out the armature. It is now considered best practice to install a circuit-breaker in preference to fuses for the protection of a motor, especially if the motor is of large size. In some cases both fuses and circuit-breaker are used.

The speed may also be regulated by varying the E. M. F. of the dynamo that supplies the motor. This, however, can only be done in special cases, because if the voltage of the dynamo is varied, it not only affects the motor but all other devices that may be operated from the same dynamo.

### SERIES-WOUND MOTORS.

**43.** These motors are constructed in the same way as series-wound dynamos; that is, the fields are excited by connecting the field coils in series with the armature, so that all the current that the motor takes from the mains flows through the field windings. The most extensive use of these motors is in connection with street railways. They are also used to some extent for operating hoists, cranes, and other machinery of this class that requires a variable speed. Nearly all series-wound motors, like shunt-wound motors, are operated on constant-potential circuits. For example, the pressure of a street-railway system is maintained approximately constant at 500 volts. Crane and hoist motors are usually operated at pressures of 110, 220, or 500 volts. Series-wound motors are operated to a limited extent on *constant-current* arc-light circuits, but the number so operated is insignificant compared with those operated on constant-potential circuits.

**44. Series-Wound Motor on Constant-Potential Circuit.**—Let *A*, Fig. 16, represent the armature of a series-wound motor connected in series with the field *F* across the mains, as shown. The pressure between the mains is maintained constant. First, we will consider the case where the motor is running light. Under this condition of load, the motor will take just enough energy from the line to make up for the losses due to friction, core losses, etc. As the armature speeds up, the counter E. M. F. increases and the current rapidly decreases. Now the field is in series with the armature, so that as the current decreases, the field strength also decreases and the armature has to run still faster to generate its counter E. M. F., which at no load is just about equal to the E. M. F. between the mains. The current necessary to supply the losses is usually very small if the motor is well designed, consequently the no-load current is very small, and the speed necessary to generate the counter E. M. F. becomes excessively high. In many cases this speed might be high enough to burst the armature.

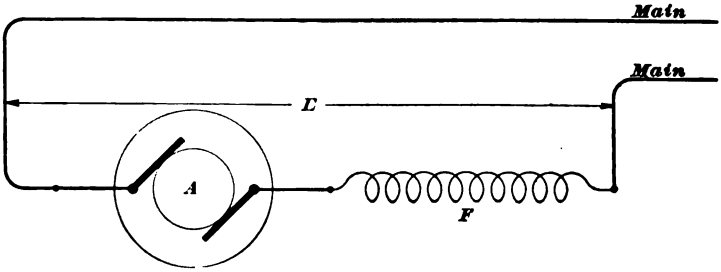

FIG. 16.

On account of this tendency to race, it is not safe to throw the load completely off a series-wound motor unless there is some safety device for automatically cutting off the current. Of course in street-railway work there is always some load on the motors, so that no injury from racing is liable to result.

**45.** When the motor is loaded, the counter E. M. F. decreases slightly, and this allows more current to flow. This current strengthens the field, and a correspondingly strong torque is produced. It should be noted here that the torque of a series-wound motor depends directly on the current that is flowing through it. The torque is proportional to the field strength and the current in the armature, but the field strength in a series-wound motor depends on the current, so that the torque depends only on the current. This quality renders the series-wound motor valuable for street-railway work, as a strong starting torque can be produced by allowing a heavy current to flow through the motor while the car is being started. Since the field strength of a series-wound motor increases as the load is applied, it follows that the speed will decrease with the load and there will be a different speed for each load. This variable speed renders the series-wound motor generally unsuitable for stationary work, such as operating machinery, etc., but is an advantage for street-railway work where a wide range of speed is desired. Series-wound motors are more substantial and cheaper to build than shunt-wound motors, on account of the fine field winding required by the latter. The field coils of series-wound motors consist of a comparatively small number of turns of heavy wire, making a coil that is less liable to burn-outs than the fine-wire shunt coils and better fitted to stand the hard service connected with all street-railway work.

If a series-wound motor be connected across the mains, the current that flows must pass through the field as well as through the armature, thus giving a good field for the armature currents to react on and produce the required starting torque. When a shunt-wound machine is used, the field must first be connected to the mains and the current then allowed to flow through the armature. If this is not done, the current will all flow through the low-resistance armature in preference to the high-resistance field when the motor is first connected, and a very small starting torque will be the result.

**46. Speed Regulation.**—The speed of a series-wound motor may be regulated either by varying the strength of the field or by inserting a resistance in series with the motor. The field strength may be regulated by having the field coils wound in a number of sections and cutting these in or out, thus varying the effective number of turns. Another method is to shunt the fields by an adjustable resistance, thereby varying the amount of current that flows through the series coils. Both these methods have been used for controlling the speed of street-car motors. In the resistance method of control, an adjustable rheostat is connected directly in series with the motor, as shown in Fig. 17, thus cutting down the E. M. F. across the motor terminals. This method has also been used quite largely on street cars and also for crane and hoist motors.

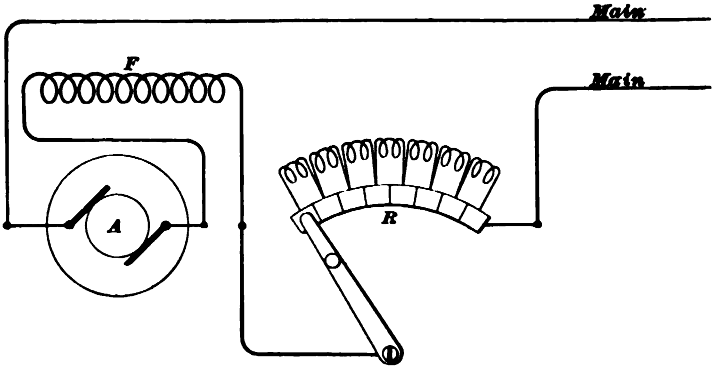

FIG. 17.

### DIFFERENTIALLY WOUND MOTORS.

**47.** These motors are essentially the same in construction as the compound-wound dynamo, except that the series coils are connected so as to oppose the shunt coils instead of aiding them as in the dynamo. The object of this arrangement is to secure constant speed when the voltage of the dynamo supplying the motor is constant. The series coils decrease the field strength slightly, and by thus weakening the field lower the counter E. M. F. sufficiently without decreasing the speed. These motors are not used as generally now as they once were, because it is found that a well-designed shunt-wound motor will give sufficiently close speed regulation for all practical purposes. Fig. 18 shows the connections of a differentially wound motor, the coils being intended to represent windings in opposite directions, one right-hand, the other left-hand.

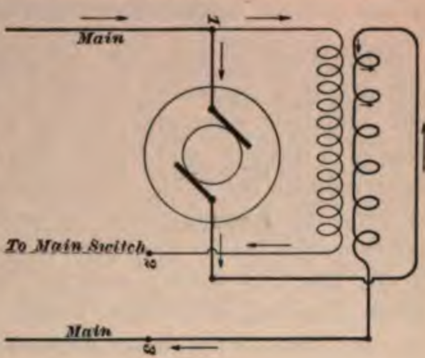

FIG. 18.

### ACCUMULATIVELY WOUND MOTORS.

**48.** When a motor is provided with a compound winding and the series coils are so connected that they *aid* the shunt coils, the motor is said to be *accumulatively wound.* This arrangement is sometimes used when it is necessary to have the constant-speed advantage of the shunt-wound motor, and at the same time have the strong starting torque of the series-wound motor. Motors of this kind are used considerably for operating printing presses or other work when the starting friction of the machine is large.

## AUXILIARY APPARATUS.

### STARTING RHEOSTATS.

**49.** When motors are operated on constant-potential circuits, it is necessary to insert a resistance in series with the armature when starting the motor. Of course, in the case of a series-wound motor, this starting resistance is also in series with the field. The resistance of a motor armature is very small in any type of motor, and in the case of a series-wound motor the field resistance is also small, so that if the machine were connected directly across the circuit while standing still, there would be an enormous rush of current, because the motor is generating no counter E. M. F. Take, for example, a shunt-wound motor of which the armature resistance is .1 ohm. If this armature were connected across a 110-volt circuit while the motor was at a standstill, the current that would flow momentarily would be $\frac{110}{.1} = 1{,}100$ amperes, the amount being limited only by the resistance of the armature. In the case of a series-wound motor, the rush of current would not be quite as bad, as the field winding would help to choke back the current, but in either case it is necessary to insert a resistance and gradually cut it out as the motor runs up to speed and generates a counter E. M. F. that is able to regulate the current.

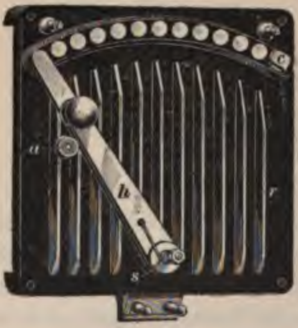

FIG. 19.

**50.** The starting rheostat, or **starting box,** as it is often called, is simply a resistance divided up into a number of sections and connected to a switch, by means of which these sections can be cut out as the motor comes up to speed. When the motor is running at full speed, this resistance is completely cut out, so that no energy is lost in it.

Fig. 19 shows a simple form of motor-starting rheostat, the resistance wire in this particular type being bedded in enamel on the back of an iron plate, while the ribs *r* on the front are intended to present additional cooling surface to the air. Starting rheostats are not designed to carry current continuously, and should therefore never be used for regulating the speed of the motor. The resistance wire is made of such a size as to be capable of carrying the current for a short time only, and if the current is left on continuously the rheostat will be burned out. The handle *h* of the rheostat shown is provided with a spiral spring *s*, tending to hold it against the stop *a*, which makes it impossible to leave the contact arm on any of the intermediate points. On the last point a clip *c* is placed to hold the arm of the rheostat.

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### SHUNT-WOUND MOTOR CONNECTIONS.

**51.** The method of connecting up a shunt-wound motor to constant-potential mains is shown in Fig. 20. The lines leading to the motor are connected to the mains through a fuse block *D*, from which they are led to a double-pole knife switch *B*. One end of the shunt field *F* is connected to terminal *1* of the motor, and one brush is also connected to the same terminal. The other field terminal is connected to the motor terminal *2*,

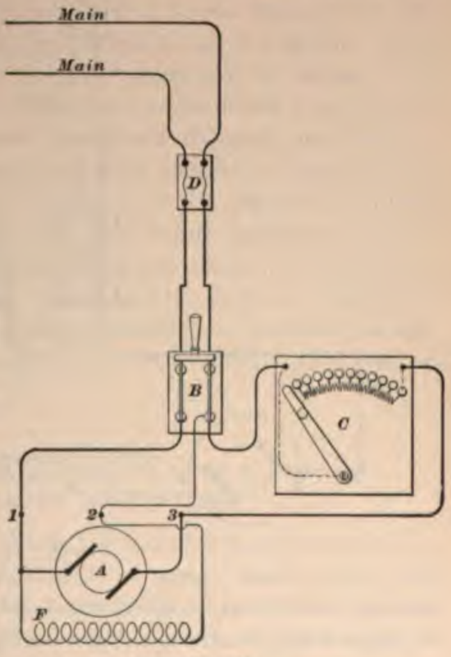


FIG. 20.

and the other brush leads to the third terminal *3*. One side of the main switch connects to terminal *1*; the other side connects to *3 through the starting rheostat C*. Terminal *2* connects to the same side of the switch as the starting rheostat. It will be seen from the figure that as soon as the main switch is closed, current will flow through the field *F*, and thus magnetize it before any current flows through the armature *A* (the first contact on the rheostat being a dead point). When the rheostat arm is moved over, current flows through the armature, and a strong starting effort is produced, because the field is already magnetized. The handle is then moved over slowly and left on the last

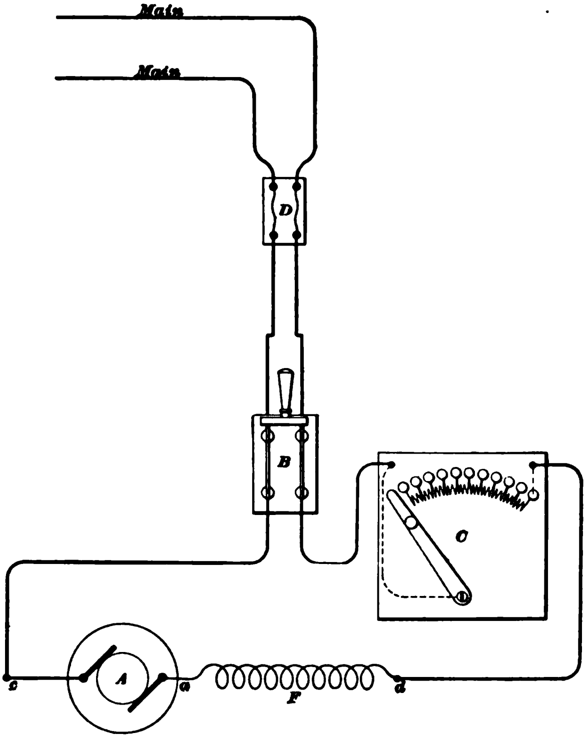


FIG. 21.

point when the motor has attained its full speed. If the motor is at all large or if there is liability of its being subjected to frequent overloads, it is preferable to use a circuit-breaker instead of the fuse block *D*. Circuit-breakers are more reliable and less troublesome than fuses.

---

## SERIES-WOUND MOTOR CONNECTIONS.

**52.** The connections for a series-wound motor are shown in Fig. 21. Connection is made to the mains through a switch and fuse block as before. The motor connections are somewhat simpler than in the last case, one terminal of the armature *A* being connected at *a* to one terminal of the field, *c* and *d* forming the two terminals of the motor. The starting rheostat *C* is simply connected in series with the armature, as shown. When a current flows through the armature, the same current also flows through the field, so that there is always a magnetic field present to produce the required starting torque. On account of the field winding acting to a certain extent like a starting resistance, series-wound motors do not require as large an amount of resistance in the starting rheostat as shunt-wound motors. This feature is of value in street-railway work, as it permits the use of a less bulky starting resistance than would otherwise be required.

---

## AUTOMATIC SWITCHES.

**53.** When the simple form of starting box is used, it is necessary to see that the handle is moved back to the off position every time that the motor is shut down or the current cut off in any way. If this is not done and the switch is thrown in, on starting up again, with the resistance all out of the circuit, there will result a heavy rush of current. In order to obviate this, motors are now usually provided with automatic boxes, the switch lever of which automatically flies to the off position when the current is shut off. They are also generally provided with an arrangement for throwing back the switch lever, and thus breaking the circuit, when the motor is overloaded. Fig. 22 shows the arrangement of an automatic box of this type, which will serve to illustrate the action of most of these automatic starting rheostats. The resistance is connected between the contact points, as shown, the arm being shown in the running position with the resistance all cut out. The contact arm is moved over against the action of a spiral spring in the hub and is held in position by a catch *a*, which fits into a notch in the hub of the lever *b*. This lever carries an armature that is held down against the action of a spring by the magnet *m*. The exciting coil of this magnet, in the case of a shunt-wound machine, is connected in series with the field; in the case of a series-wound machine, it is wound with heavy wire and

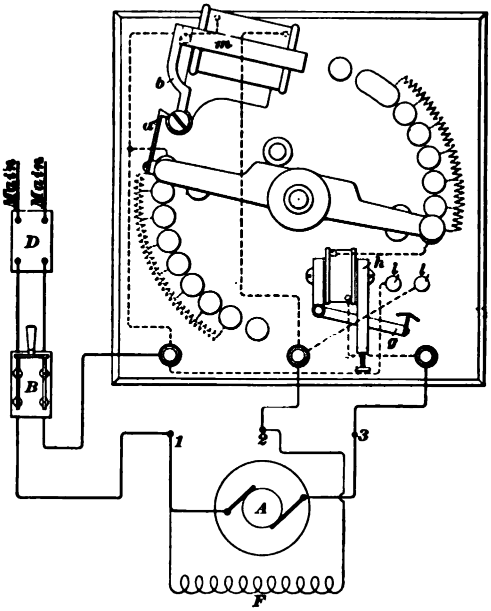


FIG. 22.

connected in series with the motor. If the current is cut off in any way, the magnet releases the armature and the switch lever flies back to the off position.

**54.** Fig. 22 also shows a device for protecting the motor against overloads. It consists of an electromagnet, the coil of which is connected in series with the armature $A$. This magnet is provided with a movable armature $g$, the distance of which from the pole $h$ may be adjusted by a screw. When the current exceeds the allowable amount, the armature is lifted, thus making connection between the pins $l$, $l$. This connection short-circuits the coil of the magnet $m$ and the lever goes to the off position.

## REGULATING RHEOSTATS.

**55.** Rheostats used for regulating the speed by being placed in the armature circuit must be designed to carry the current continuously without overheating. These rheostats must, therefore, be made much larger than starting boxes, which carry the current for a short time only. Such rheostats were used largely at one time for the control of street cars, but have now been displaced, owing to the adoption of more economical methods. All regulating rheostats, starting boxes, etc. should be installed in connection with motors in accordance with the rules of the Board of Fire Underwriters. This also applies to the size of wire that should be used for connecting up the motors and the installation of the motors themselves.

## METHODS OF REVERSING MOTORS.

**56.** It is necessary for some kinds of work to have a motor so arranged that its direction of rotation may be readily reversed. This is especially the case with street-car motors, motors for electric vehicles, etc. If the student will refer to Figs. 9, 10, and 11, he will readily see that if the direction of the current in the wire *a* be reversed while the field is left unchanged, the direction of motion will be reversed. Also, if the direction of the current in the wire is left unchanged and the field reversed, the direction of motion will be reversed. If both current and field be changed, the direction of motion will remain unchanged. It follows, therefore, that if we wish to change the direction of rotation of a given motor, we must change either the direction of the current through the armature and leave the field the same, or change the direction of the current through the field and leave the armature current the same. If both are changed at the same time, the direction of rotation will not be altered.

**57.** A shunt-wound motor may be easily reversed by reversing its field connections. Suppose a shunt-wound motor to be connected as shown in Fig. 23, and that it runs in the direction indicated by the arrow. The line is connected to terminals *1* and *3* and the field to terminals *1* and *2* when the motor is in operation and the starting resistance cut out. It is evident that reversing the line terminals *1* and *3* will not reverse the motor, because the current will be reversed in both armature and field. If, however, the field connections to *1* and *2* are interchanged, the current will be reversed through the field, while it will remain unchanged in the armature and the direction of rotation will be reversed. It is also evident that if the armature terminals *1* and *3* be reversed while the field terminals are left attached to *1* and *2*, the direction of rotation will be reversed.

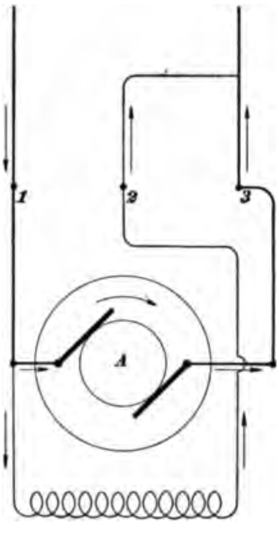


FIG. 23.

**58.** A series-wound motor will run in the same direction, no matter which of the supply lines is connected to its terminals *a*, *b*, Fig. 24. In fact, small series-wound motors may, if constructed properly and provided with laminated fields, be run on an alternating-current circuit. Reversing the line connections simply reverses the current through both armature and field, and does not, therefore, change the direction of rotation. In order to reverse the motor, either the armature terminals *c*, *d* must be interchanged, so as to reverse the current through the armature only, or the terminals *d*, *b* must be interchanged, so as to reverse the current through the field only. In street-railway work the motors are usually reversed by reversing the current through the armature, the current through the field remaining unaltered. These changes are made by means of the reversing switch placed in the car controller. All motors that are reversed during their operation should be provided with radial carbon brushes.

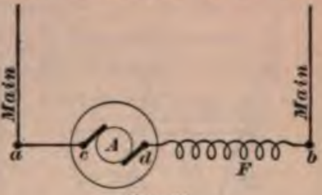


FIG. 24.

When it is desired to reverse a motor while it is running, it is very necessary to insert a resistance in the armature circuit before reversing the current through the armature. It must be remembered that the counter E. M. F. that the motor was generating just before reversal becomes an active E. M. F. and helps to make the current flow through the armature as soon as the current is reversed, and this action continues until the motor starts to turn in the opposite direction. If, for example, a 110-volt motor were reversed while running, without inserting any resistance, the effect would be the same as if the motor armature were connected directly across 220-volt mains, because the whole E. M. F. that the motor was previously generating would be effective in aiding the line E. M. F. It is best, therefore, when possible, to let the motor drop considerably in speed, or even come to a standstill, before reversing it, and where this cannot be done considerable resistance should be inserted.

**59. Reversing Switch.**—Fig. 25 shows the connections of one form of reversing switch. Two metal bars $B$ and $B_1$ are pivoted at the points $T$ and $T_1$; one is extended and supplied with a handle $H$, and the two bars are joined together by a link $L$ of some insulating material, such as fiber. Three contact pieces $a$, $b$, and $c$ are arranged on the base of the switch, so that the free ends of the bars $B$ and $B_1$ may rest either on $a$ and $b$, as shown by the full lines, or on $b$ and $c$, as shown by the dotted lines. The line is connected to the terminals $T$ and $T_1$ and the motor armature between $a$ and $b$, or *vice versa*, $a$ and $c$ being connected together.

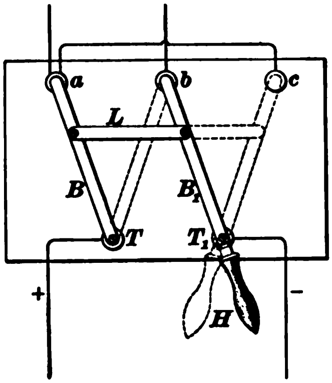
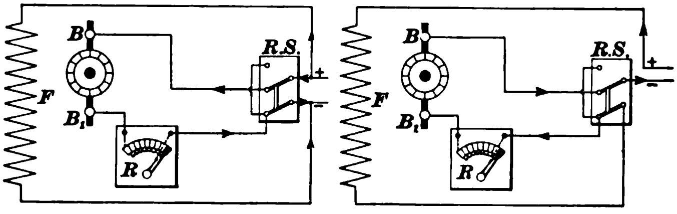


FIG. 25.

When the switch is in the position shown by the full lines, $T$ is connected to $a$ by the bar $B$, and $T_1$ to $b$ by the bar $B_1$. If the switch is thrown by means of the handle $H$ into the position indicated by the dotted lines, $T$ is connected to $b$ by the bar $B$, and $T_1$ to $a$ by the bar $B_1$ and the connection between $c$ and $a$. The direction of the current through the motor armature, or whatever circuit is connected between $a$ and $b$, is thus reversed.



(a) (b)

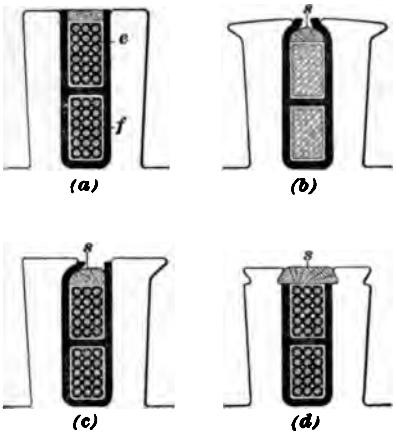
FIG. 26.

In order to reverse only the current in the armature, the reversing switch must be placed in the armature circuit only. Fig. 26 (*a*) represents the connection for a reversing shunt motor and Fig. 26 (*b*) for a reversing series motor. The line terminals are marked + and – ; $R$ is the starting resistance; $B$ and $B_1$, the brushes of the motor; and $F$, the field coil of the motor. Some manufacturers combine the starting resistance and reversing switch in one piece of apparatus.

## MULTIPOLAR ARMATURE WINDINGS.

**60.** Before leaving the subject of dynamos and motors we will take up briefly some of the more important points relating to the windings of armatures for multipolar direct-current machines. The two-pole type of machine has been replaced by the multipolar type in all but a few of the smaller sizes. Practically all the windings in use are of the drum type. This does not necessarily mean that the armature core is in the shape of a drum, because, in many modern machines, the armatures are so large in diameter compared with their length parallel to the shaft that the core takes the shape of a ring. In a drum armature, however, there is no wire passing through the center of the core and each turn represents two active conductors on the face of the armature. On the other hand, in a ring armature the turns are wound around the core instead of on the surface and each turn represents but one active face conductor. The distinction between a ring and drum winding is, therefore, more related to the way in which the winding is applied than to the actual shape of the core. Ring windings are still used on constant-current arc dynamos, but practically all other direct-current machines make use of drum windings, so that we will not consider ring windings here. It has been shown that an ordinary ring winding could be run in a multipolar field if as many brushes are provided as there are poles on the machine.

**61. Application of Winding.**—In the older styles of armatures the winding was applied by hand, the cotton insulated wire being wound directly into the insulated slots. In nearly all modern machines the coils are wound on forms and taped to hold them in shape. They are then treated with insulating compound and baked, after which they are placed on the armature. Practically all modern drum armatures are of the toothed type, i. e., the coils are held in slots between projecting teeth on the surface of the core. Fig. 27 shows a few common styles of slot in use. The straight slot shown at (*a*) is one very largely used because the coils can be easily placed in it. With straight slots, it is, of course, necessary to use band wires to keep the coils from flying out. With the overhanging teeth (*b*) and (*c*) and the notched tooth (*d*) no band wires are necessary, the coils being held down in place by the strips *s*. It will be noticed that in all these slots the conductors are divided into two groups, an upper group *e* and a lower group *f*. Each side of a coil fills only half a slot instead of a whole slot. For example, in (*a*) the group *f* represents a side of one coil and *e* the side of another coil, each coil having eighteen turns of wire. Fig. 28 shows a typical formed coil as used on a multipolar armature. The sides *a a* and *b b* lie in the slots. The spread of the coil will, of course, be determined by the number of poles on the machine, because, when the group of conductors in side *a a* is under a north pole, group *b b* must be under a



(a) (b)

(c) (d)

FIG. 27.

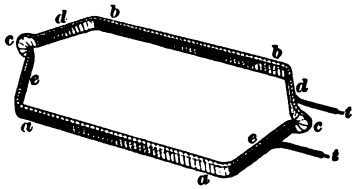


FIG. 28.

south pole. The portions *d e* project beyond the armature core and the two ends *t t* connect to the commutator.

The student will notice that the side *a a* lies in a lower plane than *b b*, the wires being given a turn at *c c* to accomplish this. Wires *a a* would, therefore, lie in the bottom part of a slot, as shown at *f*, Fig. 27 (*a*), and *b b* would lie in the top of a slot, as at *e*. The coils, therefore, lie in two layers, constituting what is sometimes called a **two-layer winding.** The object in arranging the coils in this way is to allow the end connections to pass each other easily and to lie compactly together. It also allows as many coils to be accommodated as there are slots, whereas if each side of a coil filled a whole slot, the number of coils would be only one-half the number of slots.

**62.** For armatures having a large current output, the winding is usually in the shape of copper bars of rectangular cross-section. Fig. 27 (*b*) shows a slot containing two bars. In some cases four or six bars per slot are used. Fig. 29 shows one element of a bar winding. The bars are bent as shown in Fig. 29 (*a*) and two of them are soldered together, as shown in (*b*), at the point *d*. The parts *a a* and *c c* lie in the slots and parts *b*, *b* form the cross-connections at the end. The part *b* on the front end serves both as the connection to the commutator and as the connection between the front ends of the bars, i. e., the ends of the bars next to the commutator.

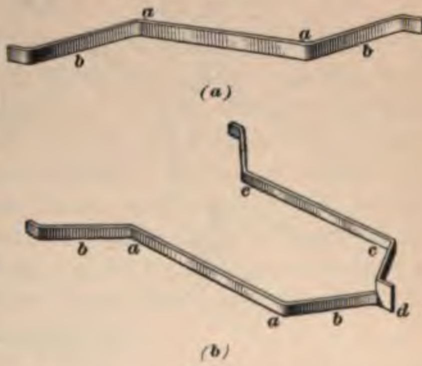


FIG. 29.

**63. Types of Windings.**—The number of different styles of winding that may be used on multipolar drum armatures is very large and it is possible to take up here only a few points regarding the most common arrangements. A complete discussion of these windings belongs to the subject of dynamo design and is beyond the scope of this Course. For convenience, we may divide multipolar drum windings into two classes, *parallel windings* and *series windings*. The significance of these terms will be seen when the two styles are explained.

**64. Elementary Principles.**—Suppose that we have an armature core *A*, Fig. 30, that is placed in a six-pole field, the poles, of course, being alternately north and south around the armature. In order to illustrate the points to be brought out, we will show only one conductor lying in each slot and draw in only two conductors under each pole in order that

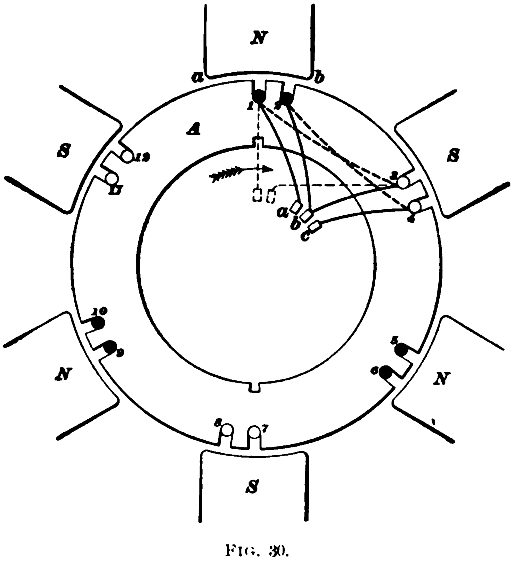


FIG. 30.

the drawing may be as simple as possible. For the present we will suppose that the conductors *1*, *2*, etc. are simply straight bars lying in the slots with their ends unconnected. Now when the armature revolves, E. M. F.'s will be induced in these conductors, and the E. M. F.'s in all the conductors passing under an *N* pole will be in one direction and those in the conductors passing under an $S$ pole will be in the opposite direction. We will assume that the E. M. F.'s in the conductors under the $N$ poles are directed down through the paper and are shown black, while those in the conductors under the $S$ poles are directed up through the paper and are shown light. The actual direction will, of course, depend on the direction of rotation of the armature, but this is not essential for the present purpose.

**65.** Now the problem in any direct-current drum winding is to connect these various conductors together and also to the commutator so that these various E. M. F.'s will add up or assist instead of oppose each other. The winding must also connect up into a closed circuit. It is evident then that we must connect the back end of an $N$ conductor to the back end of an $S$ conductor, as in Fig. 31 ($a$), because the conductors will then be in series and the E. M. F.'s will aid each other, as shown by the arrowheads. If two $N$ conductors were connected across the back, as shown in Fig. 31 ($b$), the E. M. F.'s would neutralize each other. In passing, it may be well to state that by the *back end* of an armature is meant the end away from the commutator, and the *front end* is the end next to the commutator.

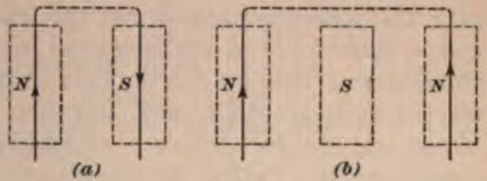


FIG. 31.

**66.** From the foregoing we see that the space spanned by the coils or bars, in connecting up an armature, must be about equal to the distance between the centers of the poles. This span is known as the **pitch**, and in a slotted armature the pitch must be about equal to the number of slots divided by the number of poles. A slot or two either way will make little or no difference as far as the operation of the machine is concerned, provided all other connections are correct; but the space spanned over by the coil should never be less than the span of the pole $a$ $b$, Fig. 30.

**67.** In connecting together the front ends of the conductors, there are two methods that may be followed—one method results in a *parallel*, *multiple*, or *lap winding*, and the other in a *series* or *wave* winding. The *multiple* or *lap* method is shown in Fig. 30. Here the front end of conductor *1* is connected to commutator bar *a* and the back end of *1* is connected to the back end of *3* under the next *S* pole, as shown by the dotted line. The front end of *3* connects to the next commutator bar *b*. In other words, one end of a coil connects to a bar and the other end of the same coil connects to the *next* bar. The front end of *2* also connects to bar *b* and the back end of *2* connects to the back end of *4*, the front end of *4* connecting to the third bar *c*. This process of connecting is continued until all the coils are connected, the last end of the last coil connecting to bar *a*, thus making the winding form a closed circuit. In Fig. 30 the student will notice that each element of the winding laps back over the preceding one, hence the name **lap winding**.

**68.** Fig. 32 shows the method of making the front connections that gives rise to a **series** or **wave** winding. Starting from bar *a* we pass down bar *1*, across the back and up *3*, the same as in Fig. 30. Instead, however, of going back to the next bar, as in Fig. 30, the end of *3* is carried forwards to a bar *d* one-third the way around the commutator and from there connects to the front end of bar *5*. The back end of *5* connects to the back end of *7* and the front end of *7* is again carried forwards to a bar *f* one-third the circumference of the commutator in advance of *d*. *f* connects to *9* and *9* to *11*, as indicated, and *11* connects to bar *b*, which is next to *a*, the point from which we started. From *b* the winding again progresses around the armature in a similar manner and comes back to *c* and so on until the winding is completed and the last terminal of the last coil is connected to *a*.

Now the back connections for Fig. 32 are the same as the back connections for Fig. 30, but the front connections are entirely different. In Fig. 30 the winding laps back on itself, while in Fig. 32 it progresses around the armature in zigzag style, thus giving rise to the term **wave winding.** Also note that in Fig. 30 there are only two conductors in series between the two commutator bars *a*, *b*, because the front end of conductor *3* connects to commutator bar *b*. On the other hand, in Fig. 32 there are six conductors (as many conductors or groups of conductors as there are poles) connected in series between *a* and *b*. These two figures are intended principally to bring out the difference in the end connections of the two styles of winding. The other features will be brought out later in connection with more complete diagrams. In actual windings connected as above, conductor *1* would lie in the bottom of the slot and *3* in the top of the slot and there would be two layers of conductors on the armature. For the sake of simplicity, however, only one conductor is indicated in each slot and these are shown as lying in the bottom of the slots. If a *single layer winding*

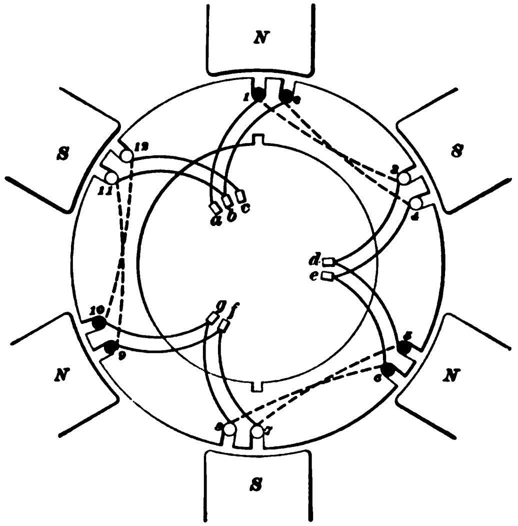


FIG. 32.

were to be used, the connection from bar *b* would be taken to the next slot beyond *2* instead of *2*, as explained later (Art. **72**), in connection with a complete diagram for a single layer winding.

**69. Arrangement of Commutator Connections.**—It will be noticed in Figs. 30 and 32 that the ends of the conductors are not connected to the commutator bar directly in front of them. The connections are brought around through an angle of about one-twelfth a circumference, or given a **lead,** as it is usually termed. This is done in this case to make the connections symmetrical, though sometimes, as on railway motors, it is done to bring the brushes into a readily accessible position. For example, the winding in Fig. 30 would work just as well if the end connections were made as shown by the light dotted lines, though we would then have one short connection and one long one instead of two of more nearly equal length. If the connections were made as shown by the light dotted lines, the brushes would be placed about in line with the center of the space between the poles; if they were made as shown by the full lines, the brushes would come about in line with the centers of the poles. The effect is practically the same as if the commutator had been given a twist on the shaft after the connections were made, thus changing the relative position of the brushes and poles from that in which one would naturally expect to find them.

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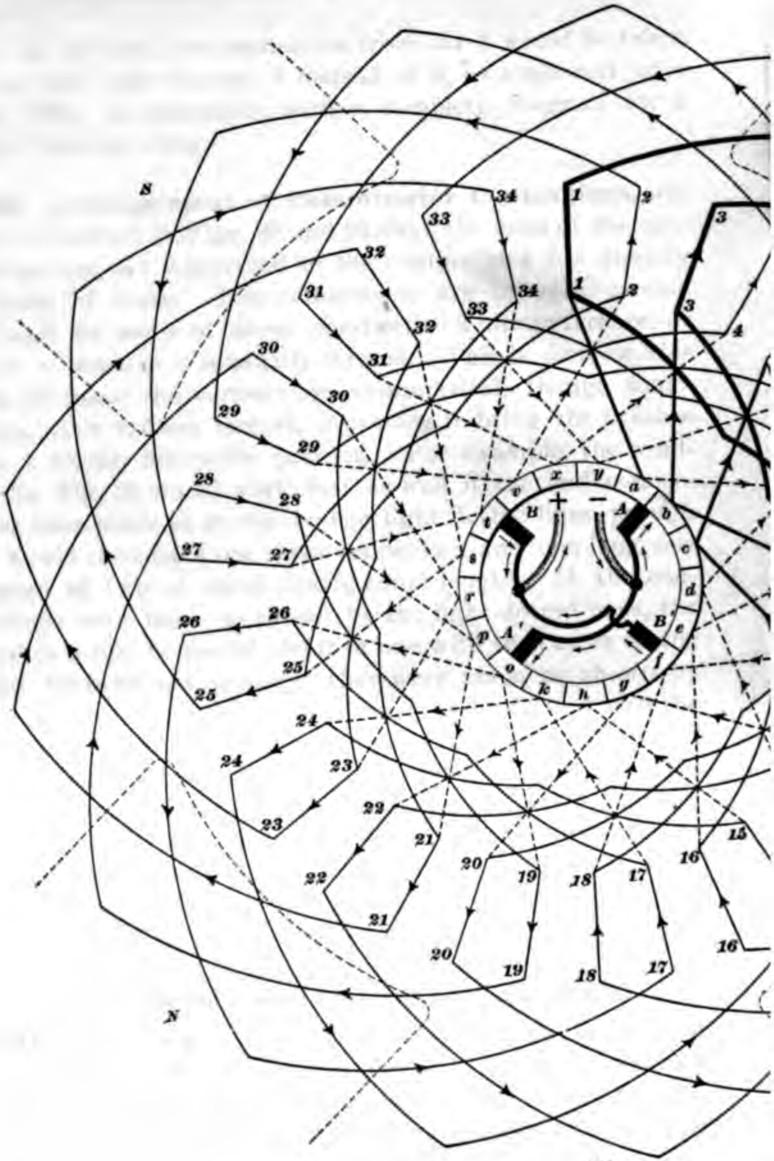
### EXAMPLE OF PARALLEL-WOUND ARMATURE.

**70.** Fig. 33 (*a*) is a diagram illustrating the method of winding and connecting a parallel or lap-wound armature for a four-pole machine. Thirty-four slots are shown, though, of course, most armatures would have a larger number than this; this number, however, is sufficient to illustrate the method of winding. The sector-shaped figures, two of which are shown in heavy lines, represent the coils. The


S
N
1
2
3
4
15
16
17
18
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20
21
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23
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26
27
28
29
30
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32
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+
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A
B
A'
B'
a
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h
k
o
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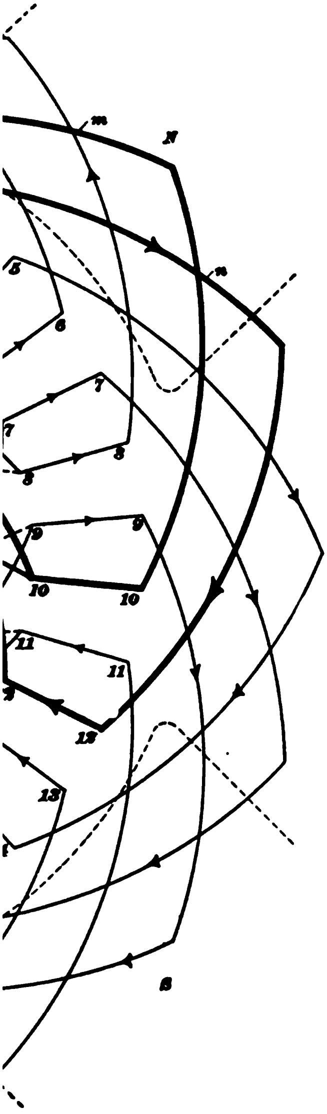
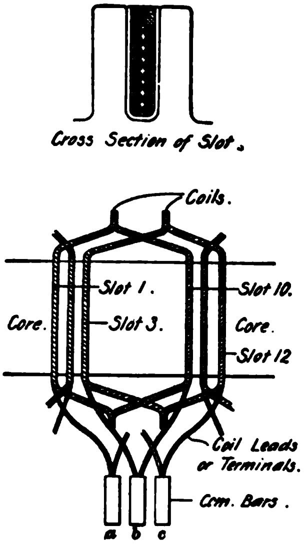
r
s
t
v
x
y

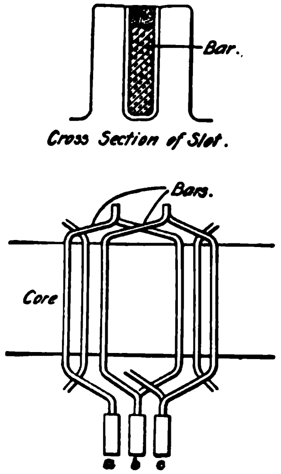
(a)

FIG. 33.


m
N
n
S


Cross Section of Slot.
Coils.
Slot 1.
Slot 10.
Core.
Slot 3.
Core.
Slot 12
Coil Leads or Terminals.
Com. Bars.
a
b
c

(b)


Bar.
Cross Section of Slot.
Bars.
Core
a
b
c

(a)

radial lines *1*, *1*, *2*, *2*, etc. represent the parts of the coils that lie in the slots and the outer curved lines represent the back ends of the coils. The inner curved lines represent the ends of the coils next to the commutator, and the brushes *A*, *A'*, *B*, *B'* are shown inside the commutator in order that the diagram may not be complicated. The straight lines running from the coils to the commutator represent the coil leads, or terminals. In this figure only one bundle of conductors has been indicated for each slot because a two-layer winding would make the diagram more complicated. With the shape of coil shown in Fig. 33 (*b*) it would be awkward to make the crossings where the coils come out of the slots, and a single layer winding would seldom be used with coils having ends shaped like those shown. However, the figure shows the method more plainly than if a two-layer winding were illustrated, and for this reason only one bundle of conductors per slot is taken. There are seventeen coils, and, hence, seventeen commutator bars and the windings are arranged in the slot about as indicated in Fig. 33 (*b*).

The same diagram could also be taken to indicate a two-layer winding with seventeen slots only, by considering the even-numbered groups as the lower groups in the slots and the odd-numbered groups as the upper ones, as indicated in Fig. 34. For example, the group of conductors *1*, *1* or one side of coil *m* would be in the top of slot *1* and the other side *10*, *10* would be in the bottom of slot *5*. In what follows, however, we will consider that we have seventeen coils arranged in thirty-four slots, there being but one group of conductors in each slot.

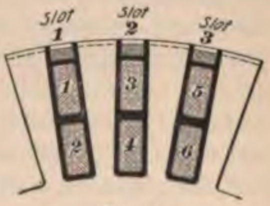


FIG. 34.

**71. Connections.**—The beginning of coil *1* is connected to bar *a*. The coils span about one-quarter of the armature and the other end of coil *m* is found at slot *10*. This end connects back to the next bar *b*. The beginning of the coil *n* (coming out at slot *3*) connects to bar *b* and the end of *n* (coming out at slot *12*) connects to *c*, and so on with all the other coils, until finally the last wire coming out of slot *8* connects to *a*, thus making a closed winding. The student should start at bar *a* and trace out the connections all around the armature or, better still, draw a diagram for himself.

The brushes will be located in a position where they will connect with the conductor in the neutral space, hence one brush will be located at *A*. Suppose we assume that *A* is a negative brush and that current is flowing in at it. In the position shown the brush *A* bridges over between bars *a* and *b*, so that coil *m* is short-circuited and there will be no current in it except, perhaps, a local current. When the incoming current reaches *a* and *b* it divides, part flowing towards *8* and part towards *3*. Bear in mind that if the current flows from the front to the back in the conductors under the north poles, it must flow from back to front in those under the south poles. Wherever two opposing currents meet a brush must be placed, so that in tracing out the current if we come to such points we will know where brushes are necessary. First we will start at *b* and take the current that flows towards *3*. The path will be *b–3–3–12–12–c–5–5–14–14–d–7–7–16–16–e–9–9–18–18–f*. Now if we go on from *f* we encounter an arrow at *11* pointing against us because *11–11* is entering under a south pole, so that a brush must be placed at *f* in order that the opposing currents can unite and flow out. Now take the current flowing from *a* towards *8*. The path is *a–8–8–33–33–y–6–6–31–31–x–4–4–29–29–z–2–2–27–27–t*. If we go on from *t* we meet an arrow in the opposite direction because *34–34* is entering under a south pole, so that there must be another positive brush at *t* to allow the opposing currents to flow out. In the above two paths we have taken in only one-half the groups of conductors on the armature, so that if we used only these three brushes we would not utilize all the winding. If, however, we add another brush *A′* we open up two more paths for the current. These are *o–19–19–28–28–p–21–21–30–30–r–23–23–32–*

*32-s-25-25-34-34* to brush *t* and out on the + armature lead. The other path from *A'* is *o-26-26-17-17-k-24-24-15-15-h-22-22-13-13-g-20-20-11-11-f* and out at *B'*. It is necessary, therefore, in a parallel or lap winding to have as many brushes or sets of brushes as there are poles—in this case four. Since brushes *B* and *B'*, *A* and *A'* are of the same polarity, they are connected together permanently by means of connecting rings. The brushes are rigidly mounted (for a four-pole machine) 90° or one-quarter a circumference apart, but the group of brushes as a whole can be shifted around the commutator in order to set them at the non-sparking point. In the armature shown in Fig. 33 (*a*) there are, then, four parallel paths for the main current, as indicated diagrammatically in Fig. 35, and for this reason the winding is called a **parallel,** or **multiple,** as well as a lap winding. If the machine had six poles, there would be six sets of brushes 60° apart instead of four sets 90° apart, and there would be six paths for the main current, and so on for any number of poles.

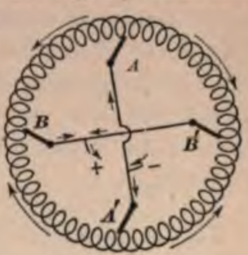


FIG. 35.

Fig. 33 (*b*) and (*c*) shows more nearly how the connections would be arranged; (*b*) shows the arrangement for a coil winding and (*c*) for a bar winding, there being but one bar in each slot.

**72. Winding Requirements.**—In Fig. 33 (*a*) the student will notice that one side of a coil is in an odd-numbered winding space and the other side in an even-numbered space; for example, coil *m* lies in slots *1* and *10*, and the number of slots spanned over is $10 - 1 = 9$. This number of slots or winding spaces spanned over is called the *pitch*. The number passed over in connecting the back ends of the conductors is called the *back pitch*, and the number passed over in connecting the front ends is called the *front pitch*. Also, in Fig. 33 (*a*) we wind from *1* to *10*, then from *3* to *12*, and so on. The even-numbered slots, *2*, *4*, *6*, etc., must be left empty for the other sides of coils wound into *27*, *29*, *31*, etc. In coming across the front of the armature, *10* is connected to *3* by way of bar *b*, so that the front pitch is 7. In windings of this kind it is a general rule that the back pitch and the front pitch are both odd numbers and differ by 2. It must be remembered that the pitch is the number of winding spaces passed over. This may or may not be the same as the number of slots passed over, because we might have more than one winding space per slot, as shown in Fig. 27. Of course, it is evident, also, that the total number of conductors, or groups of conductors, must be divisible by the number of slots, or else there would be either an empty slot or two, or an extra coil or side of a coil with no place in which to put it.

**73. Summary.**—In regard then to simple parallel-wound armatures, such as are shown in Fig. 33 (*a*), we may sum up the following:

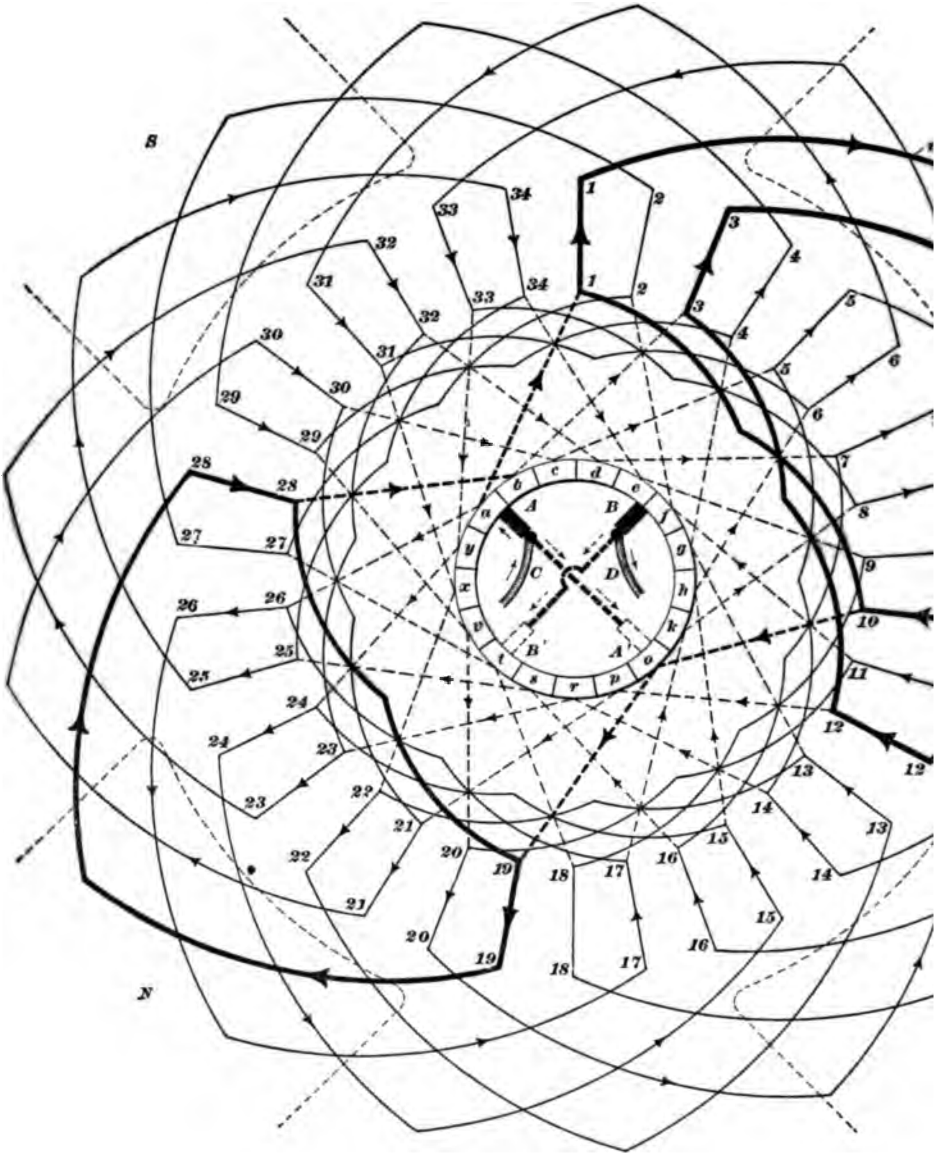
*A parallel-wound drum armature must be provided with as many sets of brushes as there are poles on the machine.*

*There are as many paths for the current through the armature as there are poles on the machine, so that the current that flows in the armature conductor is equal to the total current delivered divided by the number of poles.*

*The front pitches and back pitches must both be odd numbers and differ by 2.*

*The total number of conductors, or groups of conductors, must be divisible by the number of slots.*

Parallel-wound armatures are widely used and are especially adapted for machines that have to deliver heavy currents, because the current in the armature is subdivided and the size of the armature wire is kept down. On the other hand, they are not so well adapted for the generation of high pressures, because the voltage generated depends on the number of conductors connected in series between the brushes, and with this winding the number connected in series is only the total number divided by the number of poles.


S
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(a)

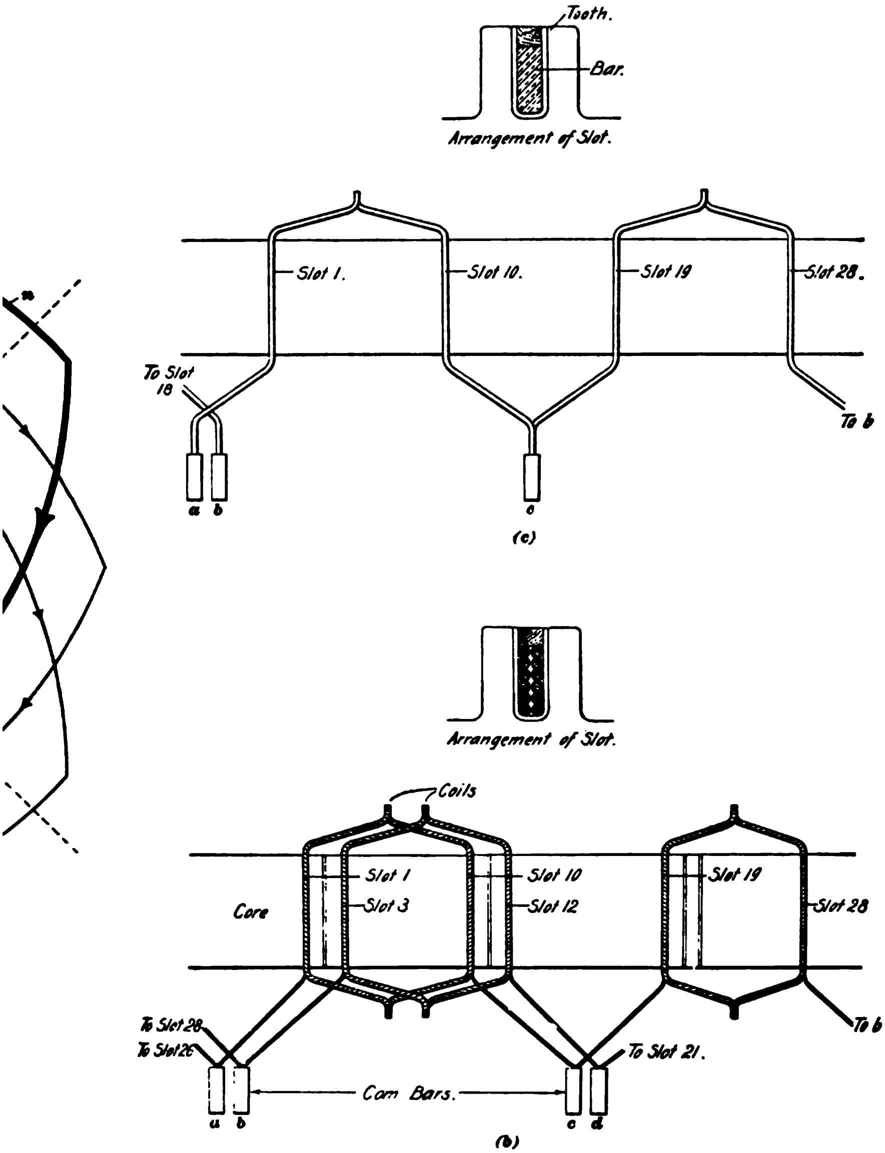
Tooth.
Bar.
Arrangement of Slot.
Slot 1.
Slot 10.
Slot 19
Slot 28.
To Slot 18
To b
a
b
c
(c)
Arrangement of Slot.
Coils
Slot 1
Slot 3
Slot 10
Slot 12
Slot 19
Slot 28
Core
To Slot 28
To Slot 26
To Slot 21.
To b
Com Bars.
a
b
c
d
(b)
m

FIG. 35.

### EXAMPLE OF SERIES-WOUND ARMATURE.

**74. Connections.**—Fig. 36 (*a*), (*b*), and (*c*) shows the same armature as in Fig. 33, provided with a series or wave winding instead of a multiple winding. The number of slots and arrangement of coils is the same as in Fig. 33, but the student must not assume that all armatures that are connected in multiple can also be connected in series, because such is not the case, as will be shown later. In Fig. 36 (*a*), the terminals from the coils have been given a backward lead of one-eighth a circumference, so that the brushes instead of falling between the pole pieces come opposite the centers of the poles, as in Fig. 33 (*a*). Starting from bar *a*, it is easily seen that the scheme of connection is the same as that already explained in connection with Fig. 32. The ends of coil *m* are connected to bars about one-half a circumference apart, i. e., bars *a* and *o*, instead of being connected to adjacent segments. Except for the method of making the connections to the commutator, the two armatures might look almost exactly alike, in fact, it is very often difficult to tell by a mere inspection whether an armature is provided with a series or a multiple winding. If, however, the terminals of a coil branch off, one to one side of the commutator and the other to the other side after leaving the slots, instead of both slanting in the same general direction, or towards the same side, as in Fig. 33 (*a*), it is usually safe to assume that the armature is series-wound.

**75.** We will place a brush *A* at a point opposite the center of one pole and assume that the current flows in at this brush and will mark the arrowheads as in Fig. 33 (*a*). Starting from bar *a* we have two paths, one of which is as follows: *a–1–1–10–10–o–19–19–28–28–b–3–3–12–12–p–21–21–30–30–c–5–5–14–14–r–23–23–32–32–d–7–7–16–16–s–25–25–34–34–e–9–9–18–18–t–27–27–2–2–f*. If we go farther than this, we encounter arrowheads in the opposite direction, so that there must be a brush at *f*. As a matter of fact, the brushes *A* and *B* are 90° apart, and bars *e* and *f* are bridged over so that the circuit *9–9–18–18–t–27–27–2–2–f* is short-circuited, and these conductors have been left without arrowheads because no current flows in them, except, perhaps, a local current. The second path starting from *a* is *a–26–26–17–17–k–8–8–33–33–y–24–24–15–15–h–6–6–31–31–x–22–22–13–13–g–4–4–29–29–v–20–20–11–11–f* to the other brush *B*.

Now if the student will examine the above two paths he will notice that every group of conductors is accounted for and that the two brushes *A* and *B* are all that are necessary for the utilization of the whole winding. Although the machine has four poles, there are but two paths through the armature and but two sets of brushes are required. This is a decided advantage in some cases, especially on railway motors, where the two under brushes would be awkward to get at. The number of conductors connected in series between the brushes is one-half the total number on the armature, so that this winding is well adapted for the generation of fairly high pressures. It is a style of winding used very largely for 500-volt railway motors and generators. Fig. 36 (*b*) and (*c*) show the connections more nearly as arranged on the actual armature, (*b*) showing the coil arrangement and (*c*) the bar winding. In both these views the armature-core surface is supposed to be straightened out flat. It may be mentioned in passing that series windings are often called **two-circuit** windings because there are but two circuits through them from brush to brush no matter how many poles the machine may have.

**76. Use of More Than Two Brushes.**—Although, as pointed out above, two brushes are all that are necessary for the operation of a series-wound armature, more than two are frequently used. This is nearly always done on large generators and motors because two sets of brushes are not capable of handling the current properly unless the commutator is made very wide and expensive, so as to give sufficient contact surface. Two additional brushes *A'*, *B'* are, therefore, provided as shown by the dotted outlines in Fig. 36 (*a*). These are at right angles to the others (for a four-pole machine) and press on bars *o* and *t*. There is no true neutral point at *o* and *t*, however, because no opposing currents meet at this point. The main current flowing in on the brush cable *C* divides, part of it entering at brush *A* and part of it at *A'*. The current flowing in at *A'* unites with that coming up to the bar *o* from *10*, *10* and flows on to *19*, *19*, as indicated by the arrowheads. The addition of brush *A'* simply relieves *A* of part of the current, but *A'* is not necessary for the operation of the machine because there is no neutral point at bar *o*. In a similar manner, the addition of brush *B'* relieves *B* of part of the outgoing current. Fig. 37 represents the winding diagrammatically. *1*, *2*, *3*, and *4* represent groups of conductors. Groups *2* and *3* are connected in series between brushes *A* and *B* and groups *1* and *4* are also connected in series and the two paths so formed are in parallel. Then we have between the two brushes *A* and *B* two parallel paths, each consisting of one-half the total number of conductors in series. The path of the current from *A* to *B* is indicated by the arrows, and it is easily seen that additional brushes can be added at *A'* and *B'* or that the machine will work with *A* and *B* alone. This diagram is only intended to show the function of brushes *A'* and *B'* a little more clearly than Fig. 36, and the connections of the coils represent those of the armature in principle only. The actual connections would, of course, be as shown in Fig. 36.

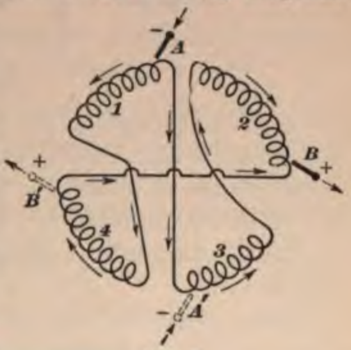

FIG. 37.

**77. Arrangement of Brushes for Six-Pole Machine.** The foregoing has been given more particularly with reference to a four-pole winding, but the winding for any number of poles is similar. The use of the series winding gives but two paths through the armature from brush to brush, no matter how many poles there may be, whereas the parallel

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winding gives rise to as many paths as there are poles. A six-pole machine *with a series winding* could be operated with two brushes 60° apart, as shown in Fig. 38 (*a*), or two additional brushes could be added and the machine operated with four brushes. If the machine had to deliver a large current, six brushes would be provided, as shown at (*c*), and six brushes would have to be used in any event if the machine had a parallel-wound armature. When more than one pair of brushes is used, brushes of similar polarity are connected together by copper rings or cables mounted on the rocker that carries the brush holders, as indicated in (*b*) and (*c*).

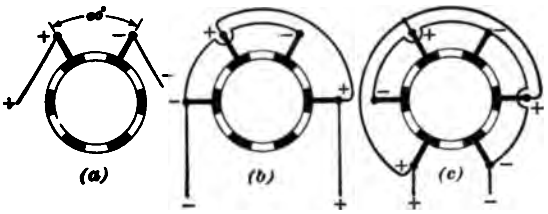

FIG. 38.

Where a machine has a series-wound armature and is provided with more than two sets of brushes, the brush that makes the best contact with the commutator will take the most current. For example, in Fig. 36, if brush *A'* made a rather poor contact, brush *A* would take more than half the current and might spark badly. In the case of a parallel-wound armature, the points where the brushes rest are true neutral points and there is not the same danger of unequal distribution of current between the brushes.

**78. Conditions for Winding.**—When an armature is to be provided with a series winding, certain conditions must be fulfilled and certain relations must exist between the number of poles, the number of winding spaces, and the front and back pitches in order that the winding shall connect up properly and form a closed circuit. For a simple series winding, like that shown in Fig. 36, these relations are as follows:

*Both the front and back pitches must be odd numbers. They may both be the same or may differ by 2.*

*The total number of winding spaces or slots (if there is but one conductor, or group of conductors, per slot) must be equal to the average pitch multiplied by the number of poles plus or minus 2.*

Or, $S = p\,y \pm 2,$

where $S$ = number of winding spaces;
$p$ = number of poles;
$y$ = average pitch.

*The total number of conductors, or groups of conductors, must be divisible by the number of conductors per slot.*

The second condition will be understood by referring to Fig. 36. Here we connect across the back from conductor *1* to *10*, hence the back pitch is 9. Across the front we connect from *10* to *19*, hence the front pitch is also 9 and the *average* pitch is also 9 $\left(\frac{9+9}{2} = 9\right)$.

The number of poles is four.

Hence, $S = 4 \times 9 \pm 2 = 38$ or 34.

Hence, with the above front or back pitches we can use 38 or 34 winding spaces and have the armature connect up all right. If we used a two-layer winding, thus utilizing two winding spaces per slot, we would have 17 or 19 slots.

**79. Cross-Connected Commutators.**—Sometimes the connections for a two-circuit or series winding are made by connecting opposite bars on a four-pole commutator or bars one-third a circumference apart on a six-pole commutator. These cross-connections on the commutator connect the armature coils in series and give rise to a two-path winding, thus allowing the machine to be run with two or more brushes. These cross-connections, however, complicate the construction, and though used considerably at one time are not now used to any great extent. The method of connection shown in Fig. 36 is simpler and represents in principle the one most commonly used for series windings.

**80.** Since a two-circuit winding provides only two paths for the current, it is evident that the current in the armature conductor will be one-half the total current supplied by the armature. The armature conductors would, therefore, be larger than would be called for if a parallel winding were used. On the other hand, there would not need to be as many conductors used to generate a given E. M. F., because one-half the total number of conductors on the armature are connected in series between the brushes. The output in watts that a given armature can deliver is, therefore, about the same no matter which style of winding is used.

**81.** The above will serve to bring out some of the main points connected with multipolar windings. As stated at the outset, there are a great many different styles of winding in use, but if the student understands the principles involved he should have little difficulty in following out any particular winding. The best way to do this is to draw diagrams similar to the figures already shown and trace out the path of the current.

# ALTERNATING CURRENTS.

(PART 1.)

## REPRESENTATION OF ALTERNATING CURRENTS.

**1.** So far all the problems we have considered in connection with electric currents have dealt with *direct currents*. In connection with the theory of the dynamo, it was shown that when a simple loop was revolved in a magnetic field so as to cut across the lines of force, a current was generated that flowed first in one direction and then in the other; in other words, an *alternating current* was generated. In order to change this alternating current to a direct current, the commutator is added.

**2.** In taking up the applications of electricity we have to deal with both direct and alternating currents. The latter have, in recent years, become of great importance because the alternating current has displaced the direct current for many lines of work, especially in the field of electric-power transmission. It is necessary to consider alternating currents by themselves, because, by reason of the fact that an alternating current is continually changing both its amount and the direction of its flow, its behavior is, in many cases, quite different from that of a direct current. The apparatus used in connection with alternating-current installations is, in general, different from that which has

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been described as used in connection with direct-current outfits and needs to be considered separately. Moreover, on account of the nature of alternating currents, they do not flow in accordance with the simple laws that govern the flow of direct currents.

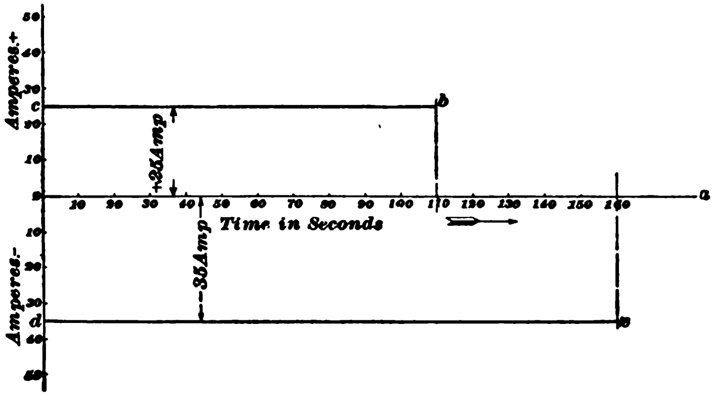

FIG. 1.

**3.** In order to study the action of alternating currents, it is absolutely necessary that there be some means of representing them on paper by means of diagrams; consequently, before going on with the study of alternating-current apparatus, it is necessary to get these methods of representation firmly fixed in mind.

**4.** The current furnished by an ordinary direct-current dynamo having a fairly large number of commutator bars is practically continuous; i. e., the current does not fluctuate to any extent as the armature revolves and, of course, never reverses its direction of flow. In continuous-current circuits, the current flows uniformly in one direction; in other words, as time elapses the value of the current does not change. This condition might be represented graphically as shown in Fig. 1. Time is measured along the horizontal line *O a*, and as the current remains at the same value, it might be represented by the heavy line *c b*; the height of this line *above* the horizontal would indicate the value of the current, i. e., +25 amperes. A current of −35 amperes, i. e., a current flowing in the opposite direction, would be represented by the heavy line *d e below* the horizontal. Time is laid off to scale (in this case each division represents 10 seconds), so that the farther we go from *0* in the direction of the arrow, the greater is the length of time that has elapsed. The line *c b* represents a current of 25 amperes, flowing uniformly in the positive direction for 110 seconds, and *d e* a current of 35 amperes flowing uniformly in the reverse direction for 160 seconds.

**5.** In the case of alternating currents, the direction of the flow is continually changing. This may be shown graphically, as in Fig. 2. In this case a current of 25 amperes flows for an interval of 1 second in the positive direction; it then reverses, flows for a similar interval in the opposite direction, and again reverses. This operation is repeated at regular intervals, as shown by the line, and any current that passes repeatedly through a set of values in equal intervals of time, such as that shown above, is known as an **alternating current.** The line *0 f f′ a g g′ b* is often spoken of as a **current,** or **E. M. F., wave,** depending on whether the diagram is used to represent the current flowing in a circuit or the E. M. F. that is setting up the current. The positive half wave *0 f f′ a* is of almost exactly the same

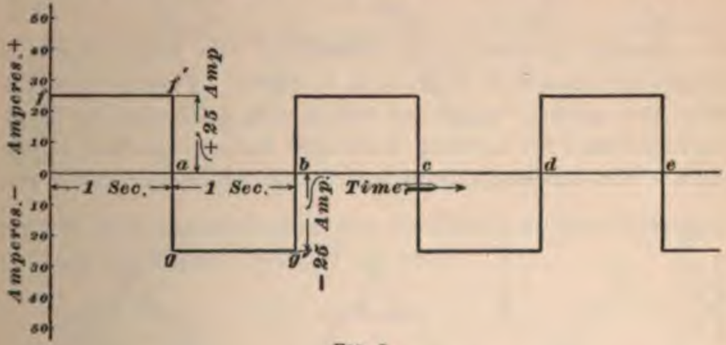

FIG. 2.

shape as the negative half wave $agg'b$ in most practical cases. Induction coils produce E. M. F.'s that have different positive and negative half waves, but in the case of E. M. F.'s produced by alternating-current dynamos, the two waves are almost identical.

**6.** The outline of the alternating-current waves usually met in practice is always more or less irregular, the shape of the wave depending largely on the construction of

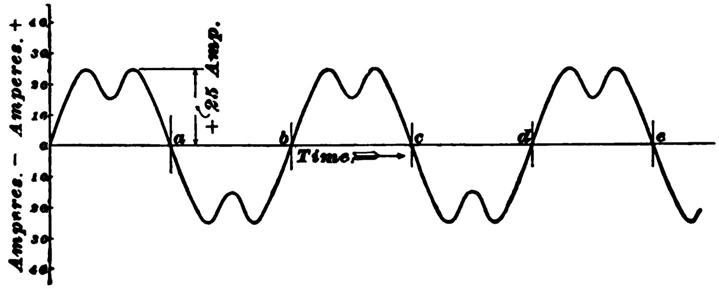

FIG. 3.

the machine producing it. Some of the more common shapes are shown in Figs. 3, 4, 5, and 6. Figs. 3, 4, and 5 show the general shape of the waves produced by some machines used for lighting work and having toothed armatures. The student should notice that while the waves are

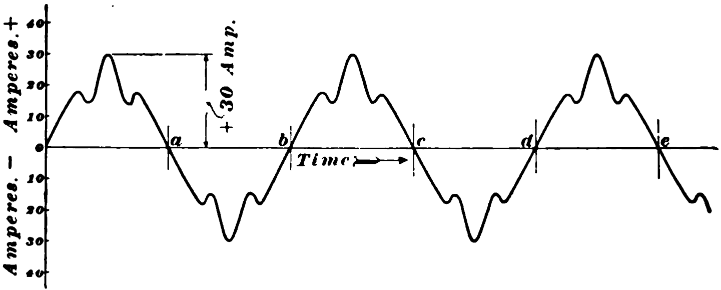

FIG. 4.

irregular, the same set of values are repeated over and over, and that the set of negative values of the current is the same as the positive, thus producing a symmetrical curve with reference to the horizontal line. Fig. 6 represents a form of wave that is commonly met, especially in the case of large alternators designed for power transmission. It will be noticed that this curve is practically symmetrical as regards both the horizontal line *O a b c* and a vertical passing through the highest point of the curve.

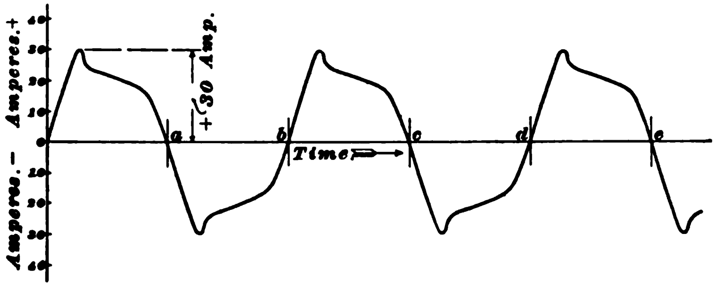

FIG. 5.

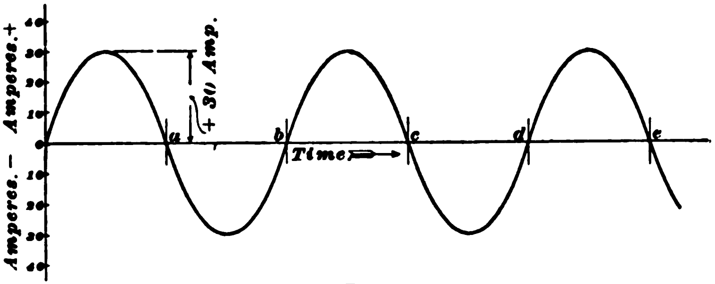

FIG. 6.

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## CYCLE, FREQUENCY, AND ALTERNATION.

**7.** In the curves shown in Figs. 3 to 6, the current passes through a set of positive values while the interval of time, represented by the distance *O a*, is elapsing, and through a similar negative set during the interval represented by the distance *a b*. This operation of passing through a complete set of positive and negative values is repeated over and over in equal intervals of time.

*The complete set of values that an alternating current passes through repeatedly as time elapses is called a* **cycle.** A cycle would, therefore, be represented by the set of values that the current passes through while the time represented by the distance *0 b* was passing.

**8.** *The number of cycles passed through in a given interval of time* (*usually one second*) *is called the* **frequency** *of the current.* For example, if the current had a frequency of 30, it would mean that it passed through 30 complete cycles, or sets of values, per second. In this case, the distance *0 b* would, therefore, represent an interval of $\frac{1}{30}$ second, and the time occupied for each half wave, or the distance *0 a*, would be $\frac{1}{60}$ second. The frequency is usually denoted by the letters $n$ or $f$, although the symbol $\sim$ is sometimes used. Frequencies used in alternating-current work vary greatly and depend largely on the use to which the current is to be put. For lighting work, frequencies from 60 to 125 or 130 are in common use. For power-transmission purposes, the frequencies are usually lower, varying from 60 down to 25, or even less. Very low frequencies cannot be used for lighting work because of the flickering of the lamps. Several of the large companies have adopted 60 as a standard frequency for both lighting and power apparatus. This is well suited for operating both lights and motors and enables both to be run from the same machine—a considerable advantage, especially in small stations. The high frequencies of 125–130 are going out of use except in stations that operate lights exclusively. When the current is used exclusively for power transmission, low frequencies of 25 or 40 are common.

**9.** An **alternation** is half a cycle. It is, therefore, represented by one of the half waves, and there are two alternations for every cycle.

Instead of expressing the frequency of an alternator as so many *cycles per second*, some prefer to give it in terms of so many *alternations per minute*. For example, suppose we have an alternator (alternating-current dynamo) supplying current at a frequency of 60, i. e., 60 complete cycles per second, or 3,600 per minute. Since there are two alternations for every cycle, the machine might be said to give 7,200 *alternations per minute*. The method of expressing the frequency as so many cycles per second is, however, the one most commonly used.

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## PHASE DIFFERENCE.

**10. Currents in Phase.**—Two or more alternating currents that have the same frequency are said to be **in phase** when they come to their maximum values at the same instant and pass through zero at the same instant. In other words, the two waves vary in unison with each other, as shown in Fig. 7. Here we have two currents *A* and *B*, one having a maximum value of 5 amperes and the other a maximum value of 3 amperes, in phase, or in step, with each other. The currents must, of course, have the same frequency, but the point to be noted is that both curves cross the horizontal line at the same points or the currents pass through zero at the same instant. Also both curves reach their maximum values at the same instant. The above two curves are shown as referring particularly to currents, but the same holds true with regard to two E. M. F's.

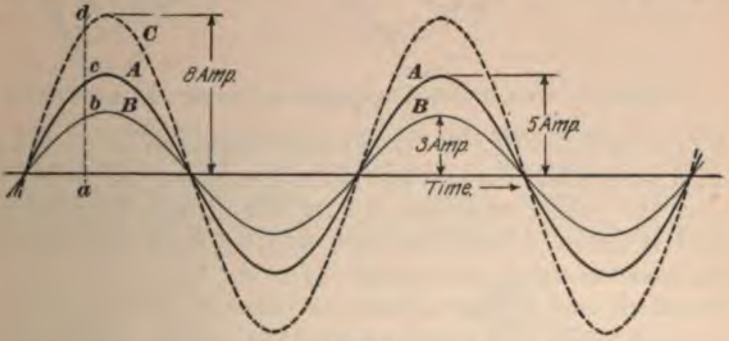

FIG. 7.

**11. Currents Out of Phase.**—Two or more currents of the same frequency are said to be **out of phase** when they do not reach their maximum values at the same instant. This will be understood by referring to Fig. 8, where the two currents represented by the curves *A* and *B* are out of phase with each other. These curves are exactly the same as those given in the last figure. They are of the same frequency, but curve *A* is displaced from *B* along the axis by the distance *a b*, with the result that the two curves do not cross the axis together nor reach their maximum values together. In other words, at the instant *c*, say, when current *A* is zero, current *B* is not zero but has a value represented by the vertical line *c d*. Now time is supposed to be measured along the horizontal line in the direction of the arrow, so that the point *c* represents a *later* instant than the point *a*, that is, curve *A* does not start until curve *B* has already reached the value represented by *c d*. The curve *A* is, therefore, said to **lag** behind the curve *B*, and the current represented by *A* is lagging behind the current represented by *B*. Sometimes the same thing is expressed by saying that the current *B* **leads** the current *A*.

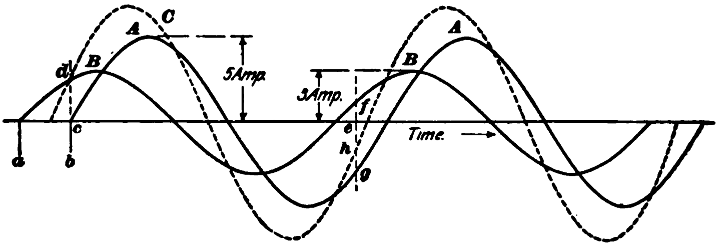

FIG. 8.

**12. Synchronism.**—Strictly speaking, two alternating currents are in synchronism when they have the same frequency; but the term **in synchronism**, as applied to either alternating currents or E. M. F.'s, implies that the two currents or E. M. F's are not only of the same frequency but are also in phase. For example, the two currents in Fig. 7 are in synchronism. One alternator is said to be in synchronism with another when its frequency is the same and when it is also in phase with the other. The word synchronism means the state of being synchronous or occurring at the same time.

In Figs. 7 and 8, the curves were both taken to represent alternating currents, but in alternating-current circuits there are cases where the current lags behind the E. M. F.; so that in Fig. 8 the curve *A* might represent a lagging current and the curve *B* the E. M. F. driving the current through the circuit. Also, under certain conditions, the E. M. F. may be ahead of the current, so that curve *B* might represent the current and curve *A* the E. M. F. It is this difference in phase that may occur between currents and E. M. F.'s that is accountable for many of the differences in behavior of alternating currents as compared with direct currents. The causes that bring about this phase difference will be studied later.

## ADDITION OF ELECTROMOTIVE FORCES AND CURRENTS.

**13.** In Fig. 7 the student should note that where the two currents are in phase, they always flow in the same direction with relation to each other. For example, when current *A* is flowing in the positive direction, so also is current *B*; and when current *A* is flowing in the negative direction, so is current *B*. The result is that the total current, as represented by the sum of the two currents, is obtained by adding the two together; that is, the two currents whose maximum values are 5 and 3 amperes give a total current whose maximum

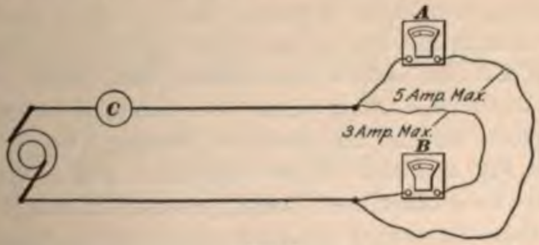

FIG. 9.

value is 8 amperes. The combined current would be represented by the dotted line. Points on this dotted curve are obtained by adding the values of the other two curves. For example, the vertical line $a\ d$ is equal to $a\ c + a\ b$. The maximum value of the curve representing the sum of the currents is $5 + 3 = 8$ amperes, and the dotted curve is in phase with the other two. Suppose, then, that we have an alternator *A*, Fig. 9, feeding two circuits *A* and *B*. The current in *A* has a maximum value of 5 amperes and that in *B* of 3 amperes. The ampere meter *C* would then indicate a current having a maximum of 8 amperes. In other words, *when the currents in A and B are in phase*, the ammeter *C* will give a reading equal to the sum of the readings given by *A* and *B*, just as would be the case with a direct current.

**14.** Now consider Fig. 8, where the currents *A* and *B* are not in phase. It is easy to see that at certain portions of the cycle the two currents are opposing each other, as at the point *e*, where current *B* has the value *e f* in the positive direction, and current *A* a value *e g* in the negative direction. The resultant current will then be the difference between the two, or *e h*, because *e h* is equal to *e g* less *e f*. We can obtain the dotted curve *C*, which represents the sum of the other two, by obtaining a number of points like *h*. Note particularly that the maximum value of this dotted curve is not 8 amperes, as in the last case, but is considerably less. Also note that the dotted curve is not in phase with either of the other two. If, therefore, we had an alternator feeding two circuits, as shown in Fig. 9, and if the currents in *A* and *B* were *out of phase* with each other, the reading given by ammeter *C* would be *less* than the sum of the readings given by *A* and *B*, and the main current furnished by the alternator would be out of phase with the currents in *A* and *B*. It is easily seen from Fig. 8 that where the currents are out of phase there are times when they oppose each other, so that it is only natural to expect that the resultant current will be less in Fig. 8 than in Fig. 7.

**15.** To summarize the foregoing we may state that:

1. *Two alternating currents or E. M. F.'s that are* **in phase** *with each other may be added in the same way as direct currents or E. M. F.'s.*

2. *If two alternating currents that are* **in phase** *be added together, the resultant current or E. M. F. is also in phase with the original currents or E. M. F.'s.*

3. *If two alternating currents or E. M. F.'s that are* **out of phase** *be added together, the resultant current or E. M. F. will be less than the sum of the two, and this resultant current or E. M. F. will be out of phase with the original currents or E. M. F.'s.*

**16.** In referring to the phase difference between two curves, it is customary to express the phase difference as so many degrees. For example, a complete cycle from *a* to *c*, Fig. 10, is taken as 360°; a half cycle, or alternation, will be 180°; and a quarter cycle, 90°. In Fig. 10, the curve *B* would be spoken of as lagging 60° behind *A*, because it does not start in until $\frac{1}{6}$ cycle has elapsed after *A* has started. This amount of lag, expressed in degrees, is called the **angle of lag**. If the angle of lag were zero, the two curves, Fig. 10, would be in phase.

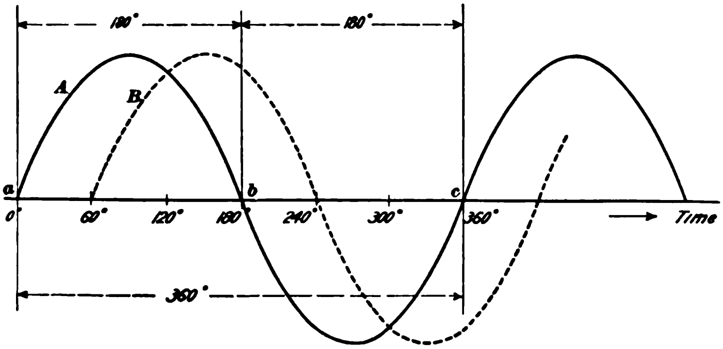

FIG. 10.

**17. Two-Phase System.**—If two currents differ in phase by 90°, they are said to be at **right angles** to each other, or in **quadrature.** In Fig. 11, suppose that we have two alternators *A* and *B*, with their armatures mounted on the same shaft and feeding two separate circuits *1*, *2*.

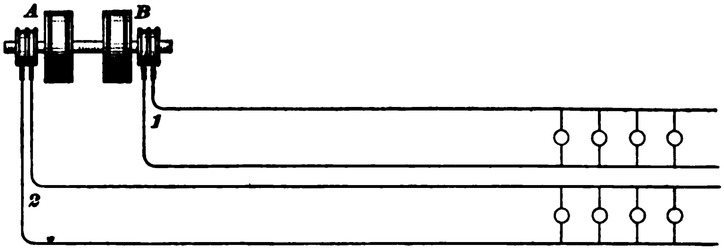

FIG. 11.

Also, suppose that the armatures are so mounted that just at the instant the current in circuit *1* is at its maximum value, the current in *2* is passing through its zero value. The curves representing the currents would then be as shown in Fig. 12. These two currents differ by 90°, or are in quadrature, or at right angles to each other. Under such circumstances it is easily seen that when No. *1* is at its maximum value *a b*, No. *2* is passing through its zero value, and *vice versa*. The system shown in Fig. 11 constitutes what is called a **two-phase** system.

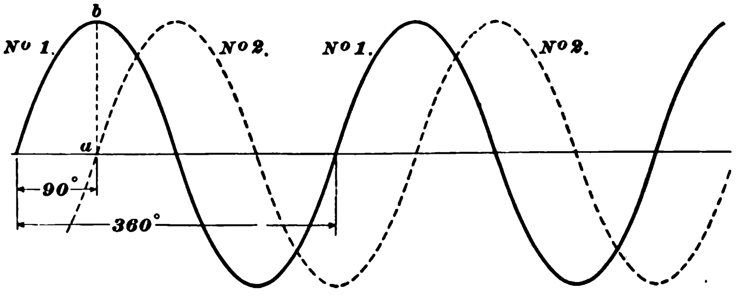

FIG. 12.

*A* **two-phase system** *is, therefore, one in which two simple* *alternating currents are used, these two currents differing in phase by 90°, or one-quarter of a cycle.*

Two currents differing in phase, as above, are usually called a two-phase current, although the use of the term two phase implies that more than one current is used. What is meant is that there are two simple currents differing in phase by 90°, or one-quarter of a cycle.

**18.** In practice it would not be necessary to use two armatures, as shown in Fig. 11, in order to generate two currents displaced in phase by 90°, although this has been done in some cases. By providing a single armature with two groups of windings properly disposed with regard to each other, the same result may be obtained. This will be explained later in connection with alternators.

**19.** Usually a two-phase system uses four wires, as shown in Fig. 11, although this is not absolutely necessary. If the central wire is made large enough, it can be made to answer as the return wire for both the others, as indicated in Fig. 13. Here $C$ is the common return wire. The current that will flow in $C$ may be obtained by adding the curves shown in Fig. 12; and as these two curves differ so much in phase, it is at once apparent that the current in $C$ will not be twice the current in the outside wires. As a matter of fact, the current in the middle wire will be 1.414 times the current in the outside wires. Also, if $E$ is the voltage between the middle and either outside wire, the voltage between the two

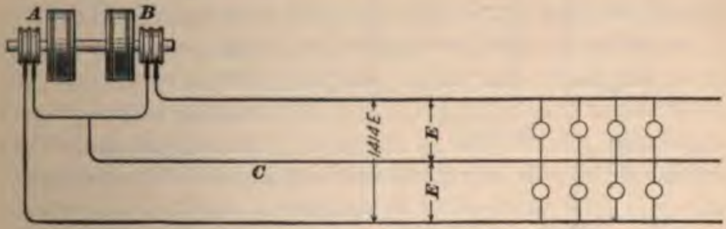

FIG. 13.

outside wires will be 1.414 $E$. It is best, however, to have the two sides of the system independent, and for this reason the four wires are generally used.

**20. Three-Phase System.**—*A* **three-phase system** *is one that uses three alternating currents that differ in phase by 120°, or one-third of a complete cycle.*

In Fig. 14 we have three alternator armatures mounted on the same shaft and supplying current to three circuits $A$, $B$, and $C$. The armatures are so fixed on the shaft with regard to each other that the E. M. F. in $B$ lags 120°, or one-third of a cycle, behind $A$. The current in $C$ lags a similar amount behind $B$, and the current in $A$ lags 120° behind $C$. In Fig. 15, if we represent the current in $A$ by the full-line curve, then the dotted curve lagging 120°, or one-third cycle, behind will represent the current in $B$. The current in $C$ will be represented by the dot-and-dash curve

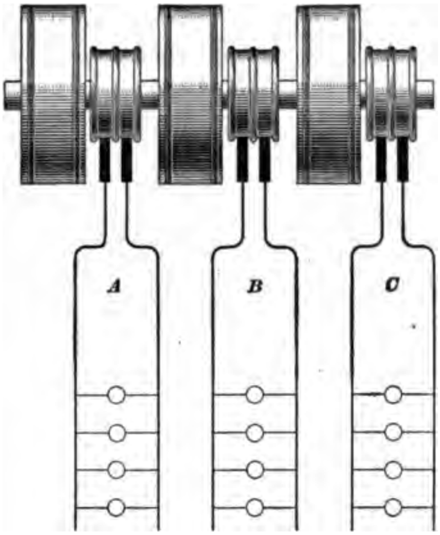

FIG. 14.

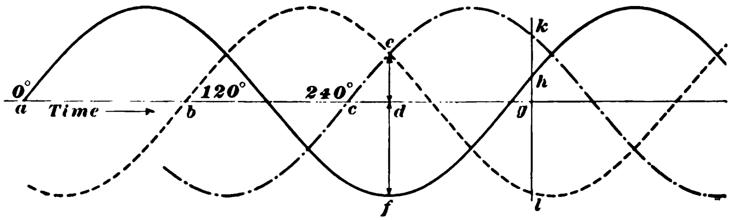

FIG. 15.

120° behind the dotted curve. The distances *a b* or *b c* are equivalent to 120° because they are equal to one-third of the distance representing a whole cycle, or 360°.

We have here three distinct alternating currents that differ in phase by 120°, and this constitutes a *three-phase system*. As in the two-phase system, these three currents, or rather the E. M. F.'s that set up the currents, can be generated by a single armature provided with three properly disposed windings. Also, we might use one wire $D$ as a common return for the other three, as shown in Fig. 16.

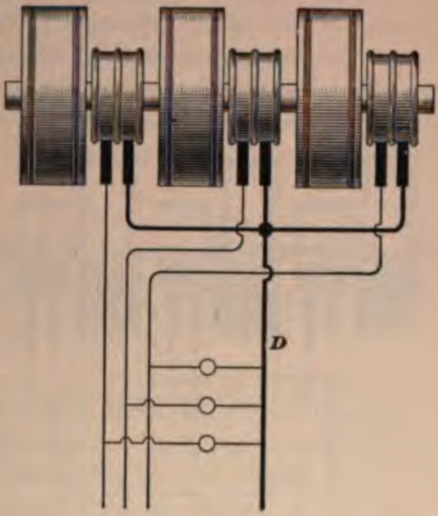

FIG. 16.

**21.** The current in the common return wire will be the sum of the three currents indicated by the curves shown in Fig. 15. Now, in Fig. 15 the curves are all of the same height; or, in other words, the currents in each of the three phases are supposed to be equal, or the system **balanced.** Under these circumstances the three curves exhibit a peculiarity that is taken advantage of to do away with the common return wire $D$. In Fig. 15 take any point $g$ and draw a vertical line cutting the three curves. If these three lines are measured, it will be found that $g l = g h + g k$. This means that the current that tends to flow in the positive direction is just neutralized by the current tending to flow in the negative direction; at the point $d$ the current in phase $A$ is at its maximum negative value, while the currents in the other two phases are each one-half as great and in the positive direction, or $df = 2\,dc$. This holds good for any points that may be taken, and the result is that the sum of the currents is always zero. Such being the case, there is no need of providing any wire for the return current and the system may be operated with three wires, as shown in Fig. 17. Under these circumstances each wire acts successively as the return wire for the other two. It must be remembered, however, that the sum of the three curves, Fig. 15, is zero only when the load is the same on all three phases. It is easily seen that if one curve is higher than the others, there will be a current in the return wire, and this wire should be provided wherever the system is liable to become unbalanced. In most cases that arise in practice, the load can be kept sufficiently near a balanced condition to render the fourth wire unnecessary, and three wires are nearly always used for the operation of three-phase systems. Where a single armature is used, as is always done in practice, the connections between *a*, *b*, and *c*, Fig. 17, are, of course, made inside the armature, thus reducing the number of necessary collecting rings to three. This will be explained more fully in connection with alternators.

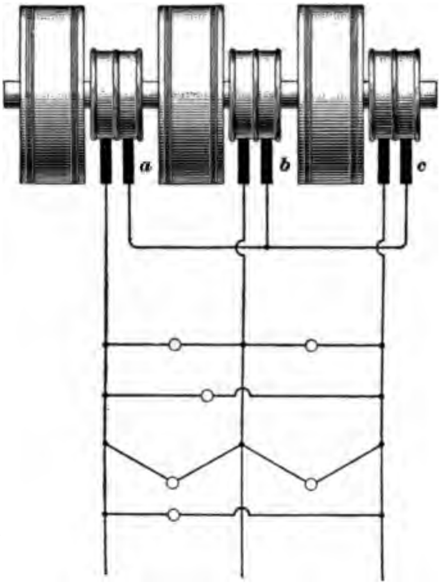

FIG. 17.

**22. Multiphase or Polyphase Systems.**—The term **multiphase**, or **polyphase**, is applied to any system that uses two or more than two alternating currents that differ in phase. Two-phase and three-phase systems are the ones most commonly used, though six-phase systems are used in a few special cases. These polyphase systems owe their extended use to the fact that a single alternating current, or a **single-phase current,** as it is usually called, is not well adapted to the operation of alternating-current motors, and where the current is used for power-transmission work, it is necessary to use two or more currents.

## MAXIMUM, AVERAGE, AND EFFECTIVE VALUES OF AN ALTERNATING CURRENT.

**23.** During each cycle an alternating current passes through a large range of values from zero to its maximum. These instantaneous values are, as a rule, used very little in calculations. But it is necessary that it should be clearly understood what is meant when a current of so many amperes is said to be flowing in a circuit or that an alternator is supplying a pressure of so many volts. When it is stated that an alternating current of, say, 10 amperes is flowing in a circuit, some average value must be implied, because, as a matter of fact, the current is continually alternating through a wide range of values. It has become, therefore, the universal custom to express the values of alternating currents in terms of the value of the continuous current that would produce the same heating effect in the circuit; for example, if the alternating current were 10 amperes, it would mean that this alternating current would produce the same heating effect as a 10-ampere continuous current.

**24.** Suppose that the curve, Fig. 18, represents the variation of an alternating E. M. F.; there are three values of this E. M. F. that are of particular importance:

1. The **maximum value,** or the highest value that the E. M. F. reaches. This value is given by the ordinate

(vertical line) *E*. This maximum value is not used to any great extent, but it shows the maximum to which the E. M. F. rises, and, hence, indicates the maximum strain to which the insulation of the alternator or any device connected to the circuit will be subjected.

2. The **average value,** which is the average of all ordinates of the curve for one-half a cycle. For example, in Fig. 18 the average ordinate of the curve *a f b* will be that ordinate *a d* that, multiplied by the base *a b*, will give a rectangle *a b c d* of the same area as the surface *a f b*. The average value taken for a whole cycle will be zero, because the average ordinate for the negative wave will be the equal and opposite of the positive ordinate. This average might be obtained by drawing a number of equally spaced vertical lines, adding them, and then dividing by the number of the lines.

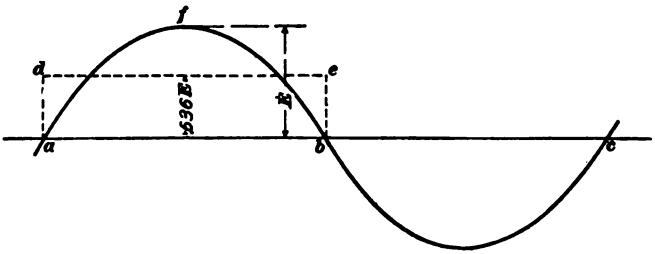

FIG. 18.

This average value always bears a definite relation to the maximum value. *If E is the maximum value, the average value is .636 E.* The average value is used in some calculations, but, like the maximum value, its use is not very extended. The relation between the average and maximum value is, however, used considerably and should be kept in mind.

3. The **effective value** of an alternating current may be defined as that value that will produce the same heating

effect in a circuit as a continuous current of the same amount. *This effective value is the one universally used to express alternating currents and E. M. F.'s;* it always bears a definite relation to the maximum value. When ammeters or voltmeters are connected in alternating circuits, they always read effective amperes or volts. This effective value is not the same as the average value (.636 max.), as might at first be supposed, but it is slightly greater, being equal to .707 times the maximum value. If a continuous current $C$ be sent through a wire of resistance $R$, the wire becomes heated, and the power expended in heating the wire is $P = C^2 R$ watts, or it is proportional to the square of the current. If an alternating current be sent through the same wire, *the heating effect is at each instant proportional to the square of the current at that instant.* The average heating effect will, therefore, be proportional to the average of the squares of all the different instantaneous values of the current, and the effective value of the current will be the square root of the average of the squares of the instantaneous values. The effective value is, for this reason, sometimes called the *square-root-of-mean-square* value. It is also frequently called the *virtual value.* Suppose, for example, a circuit in which an alternating current of 10 amperes maximum is flowing. This means that the current is continually alternating between the limits +10 amperes and −10 amperes and passing through all the intermediate values during each cycle. Now, as far as the heating or power effect of this current is concerned, it is just the same as if a steady current of .707 × 10, or 7.07 amperes were flowing, and if an ammeter were placed in the circuit it would indicate 7.07 amperes.

## RELATIONS BETWEEN VALUES.

**25.** The relation between the maximum, average, and effective values will be seen by referring to Fig. 19, the average ordinate .636 $E$ being slightly shorter than the effective .707 $E$. For convenience, the following relations are here given together; they should be kept well in mind,

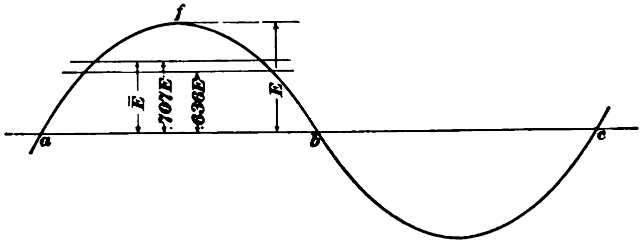

FIG. 19.

as they are used continually in problems connected with alternating-current work:

Average value = .636 maximum value.
Effective value = .707 maximum value.
Effective value = 1.11 average value.

NOTE.—The student must remember that these values only hold for currents and E. M. F.'s that vary according to the smooth waves shown in Figs. 18 and 19. These are known as *sine waves*, or sine curves. Many alternators give E. M. F. and current waves that are very close to a true sine wave, and the ordinary rules and formulas used in alternating-current work are based on the assumption that the current follows such a wave. If the student wishes further information regarding sine curves, he will find them explained in works on Trigonometry. For the present purpose such explanation is not needed and is beyond the scope of this Course.

## SELF-INDUCTION.

**26.** It has already been mentioned in connection with the subject of phase difference that very often where an E. M. F. is causing an alternating current to flow in a circuit, the current may not rise and fall in unison with the E. M. F., but may lag behind it. This effect is due to what is known as *self-induction*, and it is a direct consequence of the continual variation that the current undergoes.

It has already been shown that whenever the number of magnetic lines of force threading through a circuit is caused to change in any way, or whenever a conductor is made to cut lines of force, an E. M. F. is set up in the circuit or conductor, and the average E. M. F. so generated depends on the average number of lines of force cut per second; or, in other words, on the *rate* at which the lines are made to change. As an example, take a circular coil of wire. Lines of force may be made vary through this coil in several ways, one way, for instance, being to bring the coil near the pole of a magnet and then move it so as to cause the number of lines passing through the coil to vary. Consider the arrangement shown in Fig. 20. Here the circular coil *C*, shown in section, is placed between the poles *N*, *S* of the electromagnet, so that the lines of force indicated by the arrows thread through its center. If the coil be moved up and down in the direction of the large arrows, an E. M. F. will be generated and it will be indicated by the voltmeter *V*. The E. M. F. so generated will be alternating, and the arrangement will constitute an elementary form of alternator. The same effect would be produced if the coil were held still and the magnet moved. Both these methods are in common use in alternators, in one type the coils being mounted on the armature and revolved in front of the magnet, while in the other the coils are held stationary and the field is revolved.

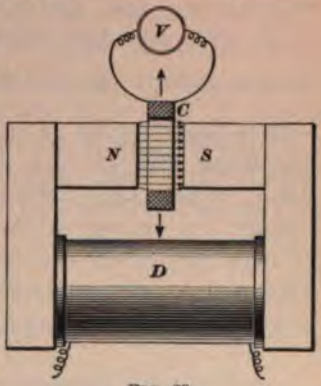

FIG. 20.

**27.** Lines of force may also be made thread a coil by sending a current through the coil itself. Take a circular coil as shown in Fig. 21. If a current is sent through such a coil, lines of force will be set up, as shown by the dotted lines. So long as the current remains steady, these lines will not change, and the current will flow through the coil just as if it were an ordinary resistance, i. e., the current will follow Ohm's law; and if the voltage applied to the terminals is $E$ volts and the resistance $R$ ohms, the current will be determined by the relation $C = \frac{E}{R}$. If, however, the current is made to vary in any way, the number of lines of force threading the coil also varies, and, hence, an E. M. F. is set up in the coil. This E. M. F. of self-induction tends to oppose any change in the current. Whenever, then, there is sent through a circuit an alternating current that can set up lines of force that will thread through the circuit, a counter E. M. F. of self-induction is set up and the current no longer flows according to Ohm's law, since the effect of the self-induction is to apparently increase the resistance of the circuit. Of course, there are no self-induction effects present in direct-current circuits, because the current is steady and no induced E. M. F.'s can be set up. Circuits containing resistance can be made that have practically no self-induction, and these are known as *non-inductive circuits*. Such circuits will behave the same with regard to alternating currents as to direct currents, i. e., the current flowing in them will be according to Ohm's law. Water resistances and incandescent lamps are practically non-inductive.

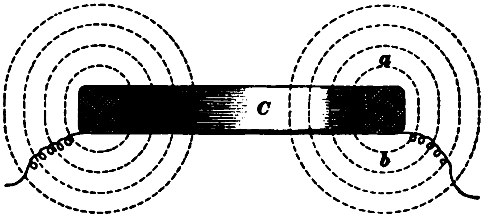

FIG. 21.

**28.** Since the induced E. M. F. always depends on the *rate at which lines of force are cut or changed*, it follows that if the coil is so situated that it can readily set up lines of force through itself, the induced E. M. F. will be large. Also, if there are a large number of turns in the coil, the E. M. F. will be large, because each of the turns will cut the lines of force threading the coil. The higher the frequency of the alternations, the more rapid will be the change in the lines, and, hence, the higher will be the E. M. F. It may then be stated that with a given current flowing through a coil, the induced E. M. F. will be proportional to the total number of lines $N$ threading the coil, the number of turns $T$, and the frequency $n$.

**29.** The total number of lines $N$ that will thread a coil when a given current is sent through it depends on the number of turns $T$ in the coil and the material by which the coil is surrounded. In the case shown in Fig. 21, where the coil is surrounded by air, the self-induction will be comparatively low, because air is a poor conductor of magnetic lines, and with a given current in the coil, a large number will not be set up through it. If, however, the coil is surrounded by iron, as shown in Fig. 22, the self-induction will be enormously increased, because lines of force can be set up very readily. The number of lines that will be set up depends, then, not only on the current, but also on some other quantity, which takes account of the location of the coil and the facility with which lines of force may be set up around it. This quantity is known as the **coefficient of self-induction** or, as it is often called, the **inductance** of the coil, circuit, or whatever piece of apparatus may be under consideration.

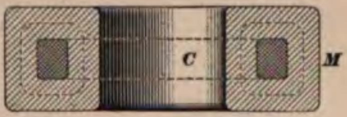

FIG. 22.

**30.** The coefficient of self-induction for any coil is obtained from the following relation:

*The product of the total number of lines N threading a coil when the current is 1 ampere and the number of turns in the coil divided by 100,000,000, or* $10^8$, *gives the coefficient of* *self-induction.* The coefficient of self-induction is usually denoted by the letter $L$. From the above, the relation given in formula **1** is obtained:

$$\frac{N \times T}{10^8} = L, \qquad \textbf{(1.)}$$

where $N$ is the number of lines corresponding to a current of 1 ampere, $T$ the number of turns, and $L$ the coefficient of self-induction. The practical unit of self-induction is called the **henry.** If a coil had a coefficient of self-induction of 1 henry, it would mean that if the coil had one turn, 1 ampere would set up 100,000,000, or $10^8$, lines through it, as seen from the formula.

The inductance $L$ for a given piece of apparatus is a constant quantity, so long as nothing but air or non-magnetic material surrounds the conductors. In order for $L$ to be constant, the magnetic permeability of the surrounding medium must be constant. If iron is present, $L$ will be nearly constant if the magnetism is not forced too high. In most practical cases, the inductance $L$ may be considered constant just as the resistance $R$ of a piece of apparatus is considered constant.

## COMPONENTS OF APPLIED ELECTROMOTIVE FORCE.

**31.** It has been shown that the effect of self-induction is to choke back the current. It also makes the circuit act as though it possessed inertia, as the current does not respond at once to the changes in the applied E. M. F., and thus lags behind. The resistance of the coil also tends to prevent the flowing of the current, but it does not tend to displace the current and E. M. F. in their phase relations. In considering the flow of current through circuits containing resistance and self-induction, it is convenient to think of the resistance and self-induction as setting up counter E. M. F.'s that are opposed to the E. M. F. supplied by the alternator. The E. M. F. supplied from the alternator or other source must then, in the case of alternating-current circuits, overcome not only the resistance, but also the self-induction. In the case of continuous-current circuits, the resistance only must be taken into account. In every case, then, where an impressed E. M. F. (the E. M. F. applied to, or impressed, on the circuit) encounters both resistance and self-induction in a circuit, it may be looked on as being split into two parts, or components, one of which is necessary to overcome the resistance and the other the self-induction.

**32. Resistance Component.**—The part of the applied E. M. F. that is required to overcome the resistance is obtained by multiplying the current by the resistance because, from Ohm's law, $E = C R$. It is evident that when the current is zero, the E. M. F. necessary to overcome the resistance is also zero, because there is no current to force through the resistance. Also, when the current is at its maximum value, the E. M. F. required to overcome the resistance is at its maximum value. *The E. M. F. required to overcome resistance is, therefore, in phase with the current.*

**33. Self-Induction Component.**—*The component of the applied, or impressed, E. M. F. that is necessary to set up the current against the induced E. M. F., or, in other words, to overcome the self-induction, is at right angles to the current and is 90°, or one-quarter of a cycle, ahead of the current in phase.*

This may be seen by referring to Fig. 23, where the heavy-line wave represents the current flowing in a coil, or circuit. The magnetism set up through the circuit will increase and decrease as the current increases and decreases, and, hence, may be represented by the light-line wave in phase with the current. Now the *induced E. M. F.* is greatest when the magnetism is changing at the most rapid rate, because then the cutting of the lines of force is greatest.

If the student will examine the curve that represents the varying magnetism, he will notice that when the curve is at its highest point, the magnetism is changing but little; for example, there is little or no change between the lines *d*, *d'*, as these two lines are of the same length. On the other hand, when the magnetism curve is passing through zero, a small change in time, as, for example, from *e* to *c*, is accompanied by a considerable change in magnetism, because the magnetism decreases from the amount at *e* to zero. In short, the rate of cutting the lines of force, or the *rate of change of the magnetism*, is greatest when the magnetism is passing through zero; hence, the *induced E. M. F.* must be a maximum when the current and magnetism are passing through zero. The induced E. M. F. is, therefore, at right angles to the current. Also, when the current is increasing in a positive direction, the induced E. M. F. must be in the negative direction, because the induced E. M. F. opposes the increase in the current. The dotted curve, Fig. 23, that represents the induced E. M. F. must, therefore, be at right angles to the current and 90° *behind* it. We are not so directly concerned with the induced E. M. F. itself as with the E. M. F. that must be applied to overcome the counter E. M. F. due to self-induction; but it is evident that this E. M. F. required to *overcome* self-induction must be the equal and opposite of the E. M. F. *of* self-induction. The dot-and-dash curve, which is the equal and opposite of the dotted curve, therefore represents the E. M. F. necessary to overcome the induced E. M. F., and it is 90° *ahead* of the current in phase. The student must not forget that the E. M. F. required to *overcome* the self-induction is the equal and opposite of the E. M. F. *of* self-induction.

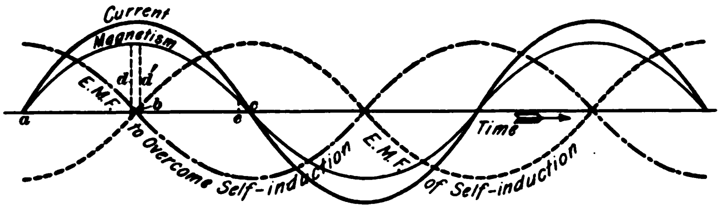

FIG. 23.

## CIRCUITS CONTAINING RESISTANCE AND SELF-INDUCTION.

**34.** If we send an alternating current through a load of incandescent lamps or through a water rheostat, we have a circuit in which there is little or no self-induction, or it is a non-inductive load. Under such circumstances the current and E. M. F. will be in phase with each other and the alternating current will behave in the same way as would a direct current. We can apply Ohm's law to find out what E. M. F. will be required to force a given current through the resistance, or we can use the same law to find out what current will flow when a known E. M. F. is impressed, or applied.

**35.** Suppose, however, that we apply an alternating E. M. F. of, say, 100 volts to a device having a resistance of 2 ohms and an inductance of 1 henry, as shown in Fig. 24. This device may be, for example, a choke coil made by winding a number of turns of insulated wire on an iron core.

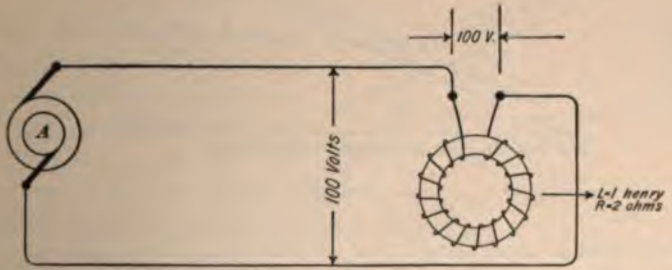

FIG. 24.

In this case, the device through which the alternator *A* sends current has both resistance and self-induction, and we can no longer apply Ohm's law to find what current will be set up by the applied pressure of 100 volts. If the current followed Ohm's law, it would be equal to $\frac{E}{R}$, or $\frac{100}{2} = 50$ amperes. As before stated, we may, in a case of this kind, look upon the E. M. F. as divided into two components, one in phase with the current and the other at right angles to the current. The part in phase with the current is equal to $C \times R$. The component at right angles to the current represents the E. M. F. necessary to overcome self-induction, and this E. M. F. depends on the inductance $L$ and the frequency $n$ of the current, because the more rapidly the current changes, the greater is the induced E. M. F. The induced E. M. F. is given by the following relation:

$$\text{Induced E. M. F.} = 6.283 \times n \times L \times C,^{*} \qquad (2.)$$

where $n =$ the frequency of the current;
$L =$ inductance of the circuit;
$C =$ current flowing in the circuit.

The impressed E. M. F. $E$ is the resultant sum of these two components and is obtained by combining the two by means of the triangle of forces, just as was done with forces

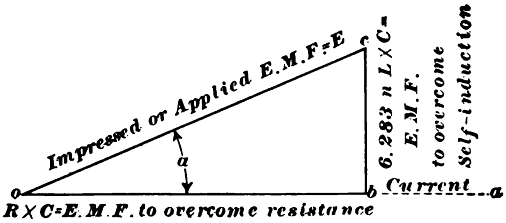
Impressed or Applied E.M.F=E
c
a
o
b
Current
a
R×C=E.M.F. to overcome resistance
6.283 n L×C=
E.M.F.
to overcome
Self-induction

FIG. 25.

as explained in *Principles of Mechanics*. For example, in Fig. 25 let $o\,a$ represent the current, i. e., the line $o\,a$ represents the current to scale, 1 inch being equivalent to a certain number of amperes; then $o\,b$ in phase with the current will represent the E. M. F. necessary to overcome resistance $= R \times C$. Then the line $b\,c$ at right angles to $o\,b$ will represent the E. M. F. necessary to overcome self-induction, and $o\,c$ will be the resultant of the two E. M. F.'s and must be equal to the applied E. M. F. $E$. The triangle $o\,b\,c$ is a right-angled triangle; hence, the square on $o\,c$ must be equal to the sum of the squares on $o\,b$ and $b\,c$.

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* The proof of this formula may be found in any of the more advanced works on Alternating Currents. The proof cannot readily be given here, as it is beyond the scope of this Course, and moreover is not necessary for an understanding of the subjects that follow. The quantity 6.283 appearing in formula **2** is equal to $2 \times 3.1416$, 3.1416 being the ratio of the circumference of a circle to its diameter. This quantity is often denoted by the Greek letter $\pi$ (pi), and in many works on Alternating Currents formula **2** is written: induced E. M. F. $= 2\,\pi\,n\,L\,C$.

Or, $$o\,c^2 = o\,b^2 + b\,c^2;$$

but $$o\,b = R\,C \text{ and } b\,c = 6.283\,n\,L\,C;$$

hence, $$o\,c^2 = (R\,C)^2 + (6.283\,n\,L\,C)^2,$$

and
$$o\,c = \sqrt{(R\,C)^2 + (6.283\,n\,L\,C)^2} = \sqrt{C^2\,[R^2 + (6.283\,n\,L)^2]}$$
$$= C\sqrt{R^2 + (6.283\,n\,L)^2}.$$

We may, then, represent the different quantities on the E. M. F. triangle as shown in Fig. 26.

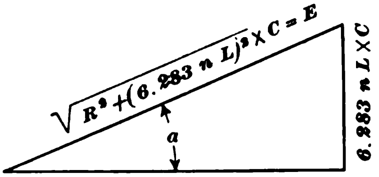

FIG. 26.

**36.** The student should study Fig. 26 carefully, because it shows the relation and amount of the three E. M. F.'s met in the great majority of alternating-current problems.

These three E. M. F.'s are as follows:

E. M. F. necessary to overcome resistance

$$= R\,C; \qquad (3.)$$

E. M. F. necessary to overcome self-induction

$$= 6.283\,n\,L\,C; \qquad (4.)$$

Impressed E. M. F., or E. M. F. necessary to overcome the resistance and self-induction combined =

$$E = \sqrt{R^2 + (6.283\,n\,L)^2}\;C. \qquad (5.)$$

Of course, the only E. M. F. that is actually present is the impressed E. M. F., but it makes matters clearer if we imagine that the applied E. M. F. is used to overcome the two other imaginary E. M. F.'s. From formula **5** we have

$$C = \frac{E}{\sqrt{R^2 + (6.283\,n\,L)^2}}. \qquad \textbf{(6.)}$$

This may also be put in the form

$$E = C\left(\sqrt{R^2 + (6.283\,n\,L)^2}\right), \qquad \textbf{(7.)}$$

and

$$\frac{E}{C} = \sqrt{R^2 + (6.283\,n\,L)^2}. \qquad \textbf{(8.)}$$

Or, ***in an alternating-current circuit, where resistance and self-induction are present, the current is equal to the impressed E. M. F. divided by the square root of the square of the resistance plus the square of 6.283 times the frequency, times the inductance in henrys.***

In other words, formula **6** is the shape that Ohm's law takes for ordinary alternating-current circuits. If the inductance $L$ becomes zero, i. e., if we have a non-inductive circuit, the quantity $(6.282\,n\,L)^2$ becomes zero and we have

$$C = \frac{E}{\sqrt{R^2}} = \frac{E}{R},$$

or when the circuit is non-inductive, the current follows Ohm's law. Or if the frequency reduces to zero, i. e., if the current becomes continuous, $n$ becomes zero and the current follows Ohm's law. The presence of self-induction has, therefore, no influence on the current so long as a direct current is used, because in this case there is no variation in the current to set up a changing magnetic field and the consequent counter E. M. F.

**37.** In formula **3**, the quantity $R$, which multiplied by the current $C$ gives the E. M. F. required to overcome resistance, is, of course, the ohmic **resistance** of the circuit, or the resistance that the wire offers on account of its inherent properties as a conductor; this resistance depends on the length, cross-section, and quality of the wire composing the circuit. The resistance is measured in ohms.

**38. Reactance.**—In formula **4**, the quantity $6.283\, n\, L$, which multiplied by the current gives the component of the applied E. M. F. required to overcome the self-induction, is known as the **reactance** of the circuit. It depends on the frequency of the current and the inductance of the circuit, which latter, in turn, depends on the amount of magnetism that the circuit is capable of setting up around itself. Reactance also is expressed in ohms.

**39. Impedance.**—In formula **5**, the quantity $\sqrt{R^2 + (6.283\, n\, L)^2}$, which multiplied by the current gives the impressed, or applied, E. M. F., is known as the **impedance** of the circuit. The impedance, as seen from this formula, depends on the values of the resistance and reactance and is equal to the square root of the sum of their squares. As seen from formula **6**, Ohm's law for alternating-current circuits containing resistance and self-induction then becomes

$$\text{Current} = \frac{\text{applied E. M. F.}}{\sqrt{\text{resistance}^2 + \text{reactance}^2}} = \frac{\text{applied E M.F.}}{\text{impedance}}. \quad \textbf{(9.)}$$

**40. Angle of Lag.**—The angle $a$, Figs. 27, 28, and 29, is the angle that the current lags behind the applied E. M. F. because the current is in phase with the E. M. F. required to overcome resistance. It is evident from Fig. 28 that if the reactance is large compared with the resistance, the angle by which the current lags behind the impressed E. M. F. will be large, and the effect of the

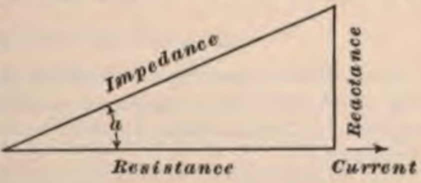

FIG. 27.

reactance on the current will be large. If, on the other hand, the reactance is very small compared with the resistance, the angle of lag will be small, as shown in Fig. 29, and the value of the current is determined largely by the resistance. If the reactance becomes zero, the angle of lag $a$ becomes zero and the impressed E. M. F. comes into phase with the current.

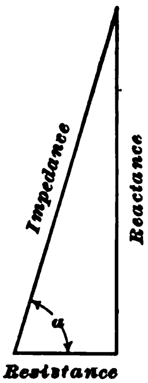

FIG. 28.

**41.** Coming back to the problem shown in Fig. 24, we can easily calculate the current that the 100-volt pressure will set up by applying formula **6**. We will suppose that the alternator generates an E. M. F. that passes through 30 cycles per second. We have then $n = 30$, $L = 1$, $E = 100$, $R = 2$;

$$\text{hence,} \quad C = \frac{100}{\sqrt{2^2 + (6.283 \times 30 \times 1)^2}}$$

$$= \frac{100}{\sqrt{4 + (188.49)^2}} = .53 \text{ ampere. Ans.}$$

If no inductance were present, or if a 100-volt direct E. M. F. were applied to the coil, the current would be $\frac{100}{2}$ = 50 amperes, so that the great effect the self-induction has on the flow of the current is easily seen.

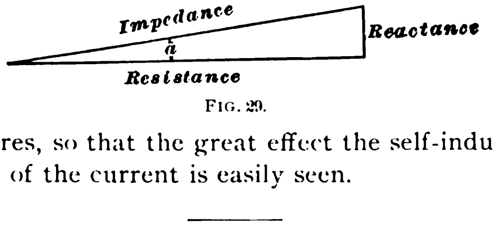

FIG. 29.

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## EXAMPLES FOR PRACTICE.

1. A 60-cycle alternator is connected to a circuit that has an inductance of .05 henry and a resistance of 10 ohms; what E. M. F. must be supplied by the alternator to force a current of 10 amperes through the circuit? Ans. 213 volts, approx.

2. A 1,000-volt 125-cycle alternator sends a current through a circuit having a resistance of 10 ohms and an inductance of .01 henry; what is the value of the current? Ans. 7.86 amperes.

## EFFECTS OF CAPACITY.

**42.** There is another property of electric circuits that must be considered in connection with the flow of alternating currents and that, like self-induction, does not enter into the consideration of the flow of continuous currents. This is the property which most circuits possess to a greater or less degree, of holding a certain charge or quantity of electricity, and is known as *electrostatic capacity;* in some cases it has a marked influence on the behavior of an alternating current flowing in the circuit. The capacity of most circuits met in practice is quite small in comparison with their resistance and inductance, consequently its effect is not usually so noticeable; however, in some cases, especially in underground cable work, these effects become important, and it is necessary to study briefly the behavior of an alternating current when capacity is present in the circuit.

If capacity is needed for any particular purpose, it is usually made up by taking a large number of sheets of tin-foil and separating them by alternate sheets of waxed paper, mica, or other insulating material. The whole mass is pressed tightly together, one set of sheets constituting one terminal and the alternate set the other, as shown in Fig. 30, where *p* represents the tin-foil sheets, *i* the insulating material, and *T* the terminal posts. Such an arrangement is called a **condenser.** It should be noticed, in passing, that there is no electrical connection between the two sets of sheets, or plates.

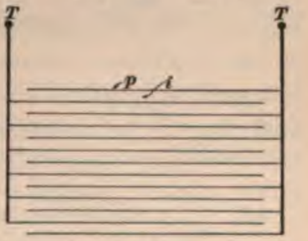

FIG. 30.

**43.** Long transmission lines have an appreciable capacity, the two wires constituting the plates of the condenser, and the capacity of underground cables is often quite large. In the latter case, the copper conductor constitutes one plate of the condenser and the outer sheath of the cable the other.

### CONDENSER CHARGES.

**44.** If a battery be connected to the terminals of a condenser, as shown in Fig. 31, a current will flow into it and the plates will become charged. This flow of current will be a maximum the instant the E. M. F. is applied, but will rapidly fall off, so that in a small fraction of a second the current will practically have ceased flowing and the condenser will be charged. This will be the state of affairs so long as the condenser remains connected to the battery; i. e., except for the instant when the battery is first connected, no current will flow, and the circuit will act simply as if it were broken. The condenser acts as if it had acquired a counter E. M. F. that tends to keep out the current, and this counter E. M. F. becomes greater until, when the condenser is charged, it is equal and opposite to that of the battery. If the battery be disconnected and the terminals of the condenser connected together, the charge will flow out and will result in a current of short duration. This current will be a maximum when the terminals are first connected, but it soon falls to zero.

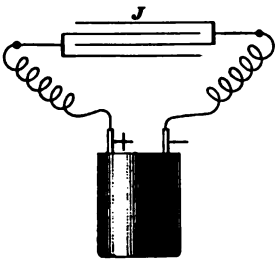

FIG. 31.

**45.** If a condenser be connected to a source of alternating E. M. F. the condenser will be alternately charged and discharged, and an ammeter inserted in the circuit will give a reading the same as if the current were actually flowing through the condenser. For example, if an alternator is connected to a long transmission line that has considerable capacity, or to a long stretch of underground cable, it will be found that an ammeter in the circuit will indicate a current even though the insulation between the lines may be perfect. This current is known as a **charging current,** because it represents the current arising from the charge that the cable, or line, alternately takes up and discharges as the applied E. M. F. rises and falls.

The effect of capacity is exactly the opposite of self-induction. Capacity tends to make the current lead the E. M. F., while self-induction tends to make it lag; so that if both are present in a circuit, one tends to neutralize the other, and in some cases, condensers have been used for this purpose. The effects of capacity, as stated before, only become appreciable on long lines or underground systems, and are not so frequently met as the effects of self-induction.

The unit of capacity is the **farad.** A condenser has a capacity of 1 farad when a charge of 1 ampere flowing for 1 second (i. e., a charge of 1 coulomb) raises the pressure across its terminals 1 volt. In other words, an applied pressure of 1 volt is able to force a charge of 1 coulomb into a condenser that has a capacity of 1 farad. The farad is too large a unit of capacity for convenient use, so the **micro-farad,** or one one-millionth of a farad, is used in practical work.

## POWER EXPENDED IN ALTERNATING-CURRENT CIRCUITS.

**46.** If a continuous current $C$ flows through a wire of resistance $R$, the wire becomes heated, and the rate at which work is done in heating the wire is proportional to the square of the current $C$ and to the resistance $R$; i. e., watts expended $= C^2 R$. Since $C = \frac{E}{R}$, we have watts $= C E$. Hence it may be stated that, in a continuous-current circuit, if we wish to calculate the watts expended, we multiply the current $C$ by the E. M. F. $E$ necessary to force the current

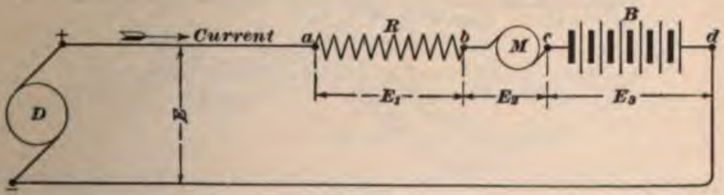

FIG. 32.

through the circuit. This is also true in a circuit where the energy expended reappears in other forms than heat. For example, we might have a direct-current dynamo *D*, Fig. 32, sending current through a circuit *a d* that consists of a resistance *R*, a motor *M*, and a storage battery *B*. The total power expended in the circuit from *a* to *d* will be the product of the current *C* and the E. M. F. *E* across the circuit. Part of this energy $= C E_1$ will reappear as heat in the resistance *R*, another part, equal to $C E_2$, will reappear as work done by the motor *M*, and the energy expended in the battery, $C E_3$, will be stored up by virtue of the chemical reactions that are caused to take place by the current.

**47.** *If an alternating current be sent through a circuit, the power expended at each instant is given by the product of the instantaneous values of the current and E. M. F.* It is seen at once, then, that the phase relation between the current and the E. M. F. will have an important bearing on the power supplied, because the value of the E. M. F. corresponding to any particular value of the current will depend altogether on their phase relation. In alternating-current circuits, therefore, the power expended cannot be obtained by simply taking the product of the volts and amperes, as is done with direct currents. The effect of the difference of phase between the current and the E. M. F. on the power expended can be illustrated by means of the curves shown in Figs. 33 to 37, inclusive. Suppose that an

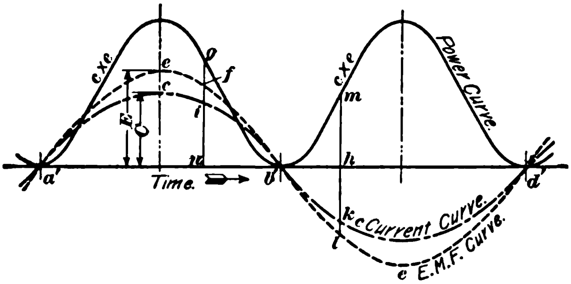

FIG. 33.

E. M. F. of maximum value $E$ is in phase with a current of maximum value $C$, as shown in Fig. 33, the current being represented by the dot-and-dash curve $c$ and the E. M. F. by the dotted curve $e$. The power at any instant, such as that represented by the point $n$, is proportional to the product of the ordinates $n\ i$ and $n\ f$ of the $c$ and $e$ curves. If an ordinate $n\ g$ is, therefore, erected at $n$ proportional to this product, $g$ will be a point on the power curve. In this way the power curve shown by the full line is constructed, and it shows the way in which the power supplied to the circuit varies with the E. M. F. and the current. It should be noticed that in this case (current and E. M. F. in phase) the power curve lies wholly above the horizontal; that is, the work is all positive, or, in other words, power is being supplied to the circuit at every instant. This would be the condition if the current were flowing through a non-inductive resistance.

**48.** Suppose, however, that the current lags behind the E. M. F. by an angle less than 90°, as shown in Fig. 34. The power curve is here constructed as before, but it is no longer wholly above the horizontal. The ordinate $f\ g$ of the current curve is positive, while at the same instant that of the E. M. F. curve $f\ e$ is negative, consequently their product is negative, and the corresponding ordinate of the power curve is below the horizontal. This means that during the intervals of time $a'\ b'$ and $c'\ d$, *negative work* is being performed; or, in other words, the circuit, instead of

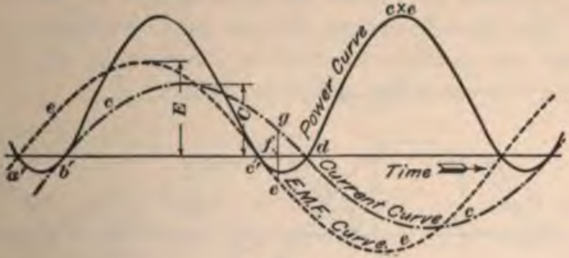

FIG. 34.

having work done on it, is returning energy to the system to which it is connected. In Fig. 35 the angle of lag has become 90°, or the current is at right angles to the E. M. F. In this case the power curve lies as much above the axis as below it, and the circuit returns as much energy as is expended in it. The total work done in such a case is, therefore, zero, and although a current is flowing, this current does not represent any energy expended. This would be nearly the case if an alternator were supplying current to a circuit having a small resistance and a very large inductance, as in this instance the current would lag nearly 90° behind the E. M. F. The primary current of a transformer working with its secondary on open circuit is a practical example of a current that represents very little energy. Such a current at right angles to the E. M. F. is, for the above reasons, known as a **wattless current,** because the product of such a current by the E. M. F. does not represent any watts expended.

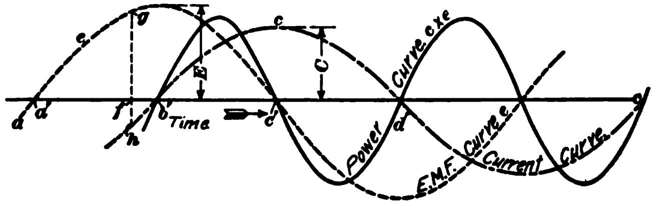

FIG. 35.

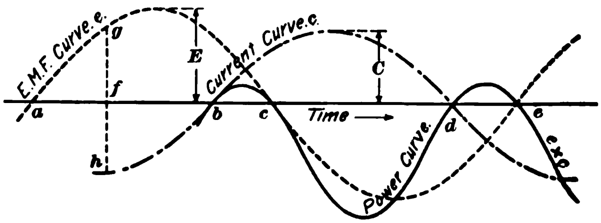

FIG. 36.

**49.** If the angle of lag becomes greater than 90°, the greater part of the work becomes negative, as shown in

Fig. 36. If the angle of lag becomes 180°, as in Fig. 37, i. e., if the current and E. M. F. are in opposition, the work done is all negative, and, instead of the alternator doing work on the circuit to which it is connected, the circuit is returning energy to the alternator and running it as a motor.

**50.** The curves in Figs. 33 to 37 show the value of the watts expended at each instant for different values of the angle of lag. What we usually wish to know is the average rate at which energy is expended and not the rate at each instant, the above curves being given simply to show the effect of the lag on the power expended. In Fig. 33, where the current and the E. M. F. are in phase, the power is always positive and the average power is obtained by taking the product of the effective values of the current and E. M. F. in just the same way as with a direct current. In Fig. 35, where the angle of lag is 90°, as much of the power curve is below the line as above it, and the result is that the average power is zero. In Fig. 34, the average power would not be zero, but it would be less than in Fig. 33. It is quite evident, then, that the true power expended in an alternating-current circuit cannot be obtained by simply multiplying the current and E. M. F. together. Another factor must be introduced to take into account the difference in phase between the current

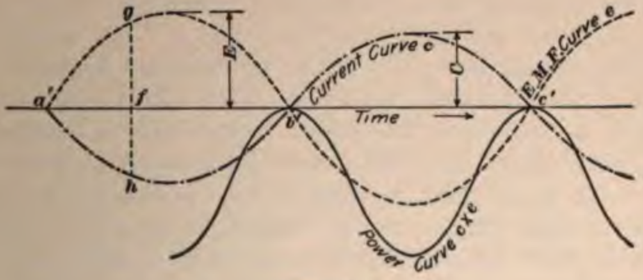

FIG. 37.

and E. M. F. This quantity is known as the **power factor,** and if it is represented by $f$, we have

$$W = C \times E \times f, \qquad \textbf{(10.)}$$

where $W =$ number of watts actually expended in the circuit;
$E =$ E. M. F. in volts;
$C =$ current in amperes;
$f =$ power factor.

The product $C \times E$ is sometimes called the **volt-amperes,** or **apparent watts,** supplied to the circuit, while $W$ is the actual number of watts or **real** watts supplied. It follows, then, from formula **10** that

$$\text{power factor} = \frac{\text{real watts}}{\text{apparent watts}}. \qquad \textbf{(11.)}$$

**51.** For continuous-current circuits and for alternating-current non-inductive circuits, the current and the E. M. F. are in phase and the power factor is 1. The watts are, therefore, obtained by simply multiplying together the ammeter and voltmeter readings. Where alternating-current motors are operated, the power factor may be less than 1, say, from .80 to .90. The power factor may vary from 1 to zero. It would have a value of zero in case the E. M. F. were at right angles to the current, as shown in Fig. 35, because there the actual power expended is zero; although a considerable E. M. F. and current may be present. Of course, a zero power factor is seldom, if ever, met in practice, but power factors anywhere from .5 up to 1 are common. The power factor of motors, transformers, and other alternating-current devices varies to some extent with the load. The effects of a low-power factor on alternating-current circuits will be considered later. For the present the student should note carefully the effect that the difference in phase between the current and the E. M. F. has on the power, and also that the product of volts and amperes in an alternating-current circuit will in most cases give a number of apparent watts that will be considerably greater than the number of actual watts.

**Example.**—A current of 10 amperes at a pressure of 500 volts is supplied to an alternating-current circuit that has a power factor .85; what is the actual number of horsepower furnished?

**Solution.**—From formula **10,** we have

$$W = 10 \times 500 \times .85 = 4{,}250,$$

and since 1 horsepower = 746 watts,

$$\text{H. P.} = \frac{4{,}250}{746} = 5.7, \text{ nearly. Ans.}$$

# ALTERNATING CURRENTS.

(PART 2.)

## SINGLE-PHASE ALTERNATORS.

### GENERAL CHARACTERISTICS.

**1.** Dynamo-electric machines used for the generation of alternating E. M. F.'s are known as **alternators.** It was shown in the theory of the dynamo that the E. M. F. generated in the armature of a direct-current dynamo is essentially alternating, and that the commutator is supplied to preserve the relation of the external circuit so that the current in it may be direct. It follows, therefore, that if the proper terminals of a continuous-current armature were connected to two collector rings in place of a commutator, the current furnished would be alternating. In the majority of cases, however, alternator armatures are not wound in the same way as are those for continuous current, and the E. M. F. is more generally produced by moving a set of

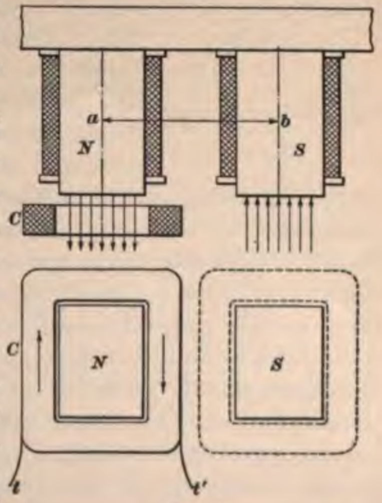

FIG. 1.

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coils past pole faces rather than by revolving loops or coils, as is done in direct-current drum armatures. In other words, the movement of the coils is best looked on as one of translation rather than rotation. As an example of this, consider a horseshoe electromagnet, shown in Fig. 1. When such a magnet is excited by means of the coils on its two limbs, lines of force flow from the north pole *N* into the south pole *S*, as indicated by the arrows. The two pole faces are shown in the lower diagram, and the rectangular coil of wire *C* is supposed to be moved across the pole face *N* to the position shown by the dotted outline in front of *S*. When the coil is in the position shown under the north pole, a small movement of the coil to the right will not cause a very large change in the number of lines threading it, consequently only a small E. M. F. will be induced. While the conductors are moving under the pole pieces, the E. M. F. will be practically uniform if the field is uniform, and when the coil has reached the position shown by the dotted line, the E. M. F. will again be zero. The E. M. F. has, therefore, passed through one alternation, or half cycle, while the coil has been moved through the distance *a b*. This E. M. F. curve may be of the shape shown in Fig. 2, the portion at *y* being fairly uniform while the conductors are moving under the poles; or it may have a different shape, depending on the shape of the coil and pole pieces as well as on the way in which the magnetic lines are distributed. No matter what may be the shape of the curve *a y b*, the *E. M. F. passes through one alternation when the coil is moved a distance equal to that from the center of one pole to the center of the next.* If the coil *C* be moved back from *S* to *N*, the same set of values of the E. M. F. is generated in the opposite direction; hence, by moving the coil from *N* to *S* and back,

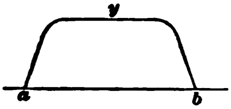

FIG. 2.

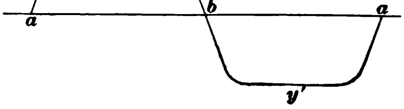

FIG. 3.

the E. M. F. passes through one complete cycle, as shown in Fig. 3. The arrangement shown in Fig. 1 would, therefore, constitute an elementary alternator, and the E. M. F. would be set up by movements of the coil back and forth across the pole faces, there being no rotation at all. Instead of moving the coil back and forth, the same effect could be produced by moving the coil forwards, continuously, in front of a row of poles, as shown in Fig. 4. As the coil *C* moves past the poles, it cuts the lines of force first in one direction and then in the other,

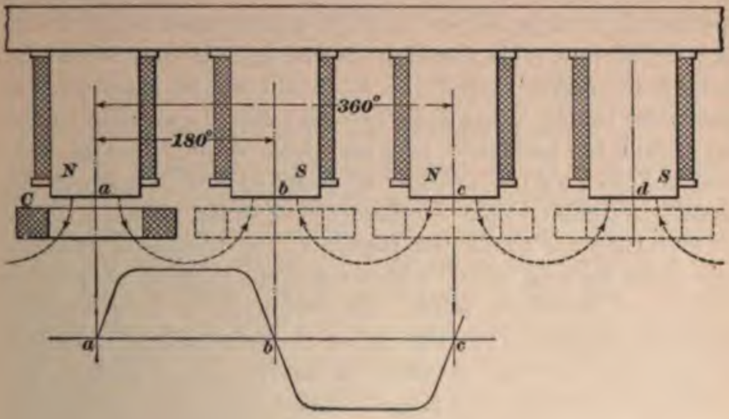

FIG. 4.

thus producing the alternating E. M. F. represented by the curve below. It should be noted that while the coil moves through the distance between one north pole and the next pole *of the same polarity*, the E. M. F. passes through one complete cycle. The distance from *a* to *c*, therefore, corresponds to 360° on the E. M. F. curve, and *a b* to 180°. For every *pair of poles* passed, the E. M. F. passes through a *complete cycle of values;* hence it follows that the *number of cycles per second or the frequency of an alternator is equal to the number of pairs of poles that the armature winding passes per second.* If the number of poles on the machine is $p$, the number of pairs of poles is $\frac{p}{2}$, and if the coil is moved past the poles $s$ times per second, the frequency $n$ will be

$$n = \frac{p}{2} s. \qquad (1.)$$

**2.** Instead of the single coil $C$, Fig. 4, being used by itself, three other coils, shown dotted, might be connected in series or parallel with $C$ and the four moved together in front of the poles. If the coils were connected in series, it is evident that the total E. M. F. produced would be increased, because all the E. M. F.'s generated in the turns of the different coils would be added up. If they were connected in parallel, the E. M. F. would be the same as that produced by the single coil, but the current-carrying capacity would be increased, because there would then be four circuits to carry the current in place of one. It should be noted particularly that no matter how many coils there are or how they are connected together, the frequency remains the same so long as the speed $s$ and the number of poles is constant. In other words, the *frequency* of an alternator does not depend on the way in which the armature is wound. Connecting the coils in series is equivalent to making the winding of one coil of a large number of turns; connecting them in parallel amounts to the same thing as winding in one coil with a heavy conductor. As long, therefore, as the coils are all moved simultaneously, as is always the case, the frequency is not affected in any way by the scheme adopted for winding and connecting up the armature.

**3.** It is evident that an alternating E. M. F. would be set up in the coil or set of coils, Fig. 4, if the magnet were moved and the coils held stationary. Also, both coils and magnet might be stationary and an E. M. F. still be induced by causing the lines of force threading the coils to vary. These three methods give rise to the following three classes of alternators:

1. Those in which the armature coils are moved relatively to the field magnet.

2. Those in which the field is moved relatively to a fixed armature.

3. Those in which the magnetic flux passing through a fixed set of coils is made to vary by moving masses of iron, called *inductors*, past them.

For convenience in referring to alternators, we will suppose that the armature is the revolving part and that the field is fixed, though it must be remembered that actual machines may be built with any of the three arrangements mentioned above.

## CONSTRUCTION OF ALTERNATORS.

**4.** The most common type of alternator is that in which the coils are mounted on a drum and revolved in front of a magnet consisting of a number of radial poles. Alternator armatures may be of the ring, drum, or disk type, but the drum style is used almost exclusively in America. If we suppose the poles, Fig. 4, to be bent into a circle and the coils mounted on a drum revolving within the poles, we will have one of the most common types of alternators. This arrangement is shown in Fig. 5, except that in this case the machine is provided with eight radial poles and eight coils on the armature, giving a style of winding in common use for machines used on lighting circuits. In this case there are as many coils on the armature as there are poles on the machine; but a winding might easily be used in which there would be only half as many coils as poles. There is a large variety of windings suitable for alternators, and the designer must select the one best suited to the work that the machine will have to do. In Fig. 5 the coils $C$ are shown bedded in the slots $p$ on the circumference of the iron core $P$, which is built of thin iron stampings. These coils are heavily taped and insulated and are secured in place by hardwood wedges $w$.

This makes a style of armature not easily injured, and the use of the dovetailed slots and wooden wedges does away with the necessity of band wires. As the armature revolves, the coils sweep past the pole faces, and the E. M. F. is generated in the manner shown in Fig. 4, i. e., the movement of the coils relative to the pole pieces becomes one of translation rather than of rotation.

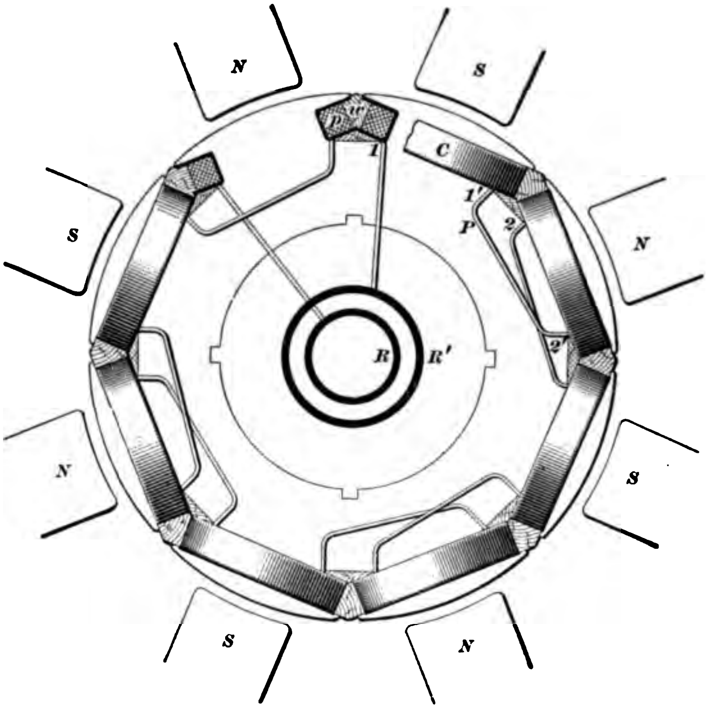

FIG. 5.

**5.** Alternators are generally required to furnish a high voltage, and, in consequence, the armature coils are usually connected in series. Care must be taken in connecting such windings to see that the coils are so connected that none of the E. M. F.'s oppose one another. By laying out a diagram of the winding, the manner in which the coils must be connected will be easily seen. This has been done in Fig. 6, which shows diagrammatically the winding of the armature in Fig. 5. The coils are represented by the heavy sector-shaped figures and the connections between them by the lighter lines. The circles in the center represent the collector rings of the machine and the radial lines that part of the coil that lies in the slot, that is, the part in which the E. M. F. is generated. The circular arcs joining the ends of the radial lines represent the ends of the coils that project beyond the laminated armature core.

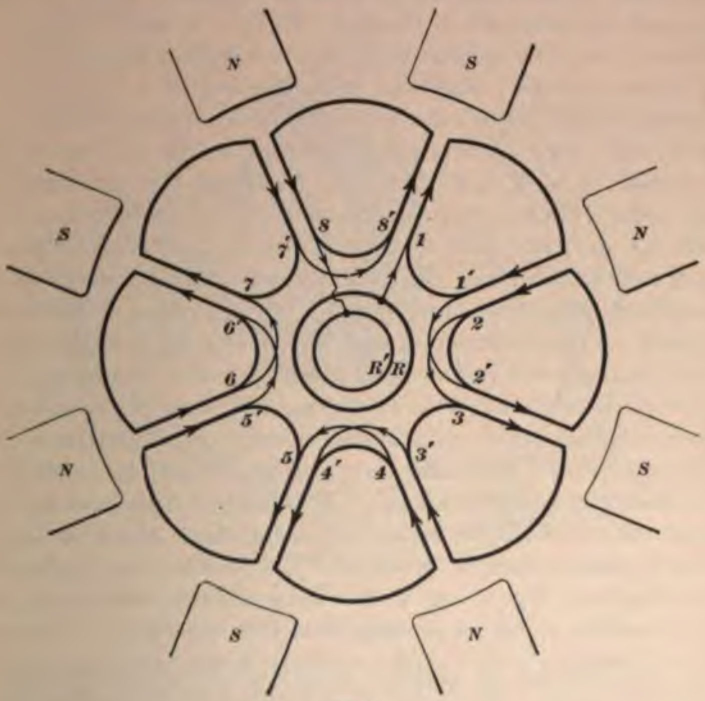

FIG. 6.

The drawing is made to show the coils at the instant the conductors in the slots are opposite the centers of the pole pieces. At this instant the E. M. F. will be assumed to be at its maximum value, and we will suppose that the direction of rotation is such that the conductors under the north poles have their E. M. F.'s directed from the back of the armature towards the front. These E. M. F.'s will be denoted by an arrowhead pointing towards the center of the circle, since the inner end of the radial lines represents the front or collector-ring end of the armature. The E. M. F.'s in the conductors under the south poles must be in the opposite direction, or pointing away from the center. After having marked the direction of these E. M. F.'s, it only remains to connect the coils so that the current will flow in accordance with the arrows. Starting from the collector ring *R* and passing through the coils in the direction of the arrows, it is seen that the connections of every other coil must be reversed; i. e., if *1*, *1'*, *2*, *2'*, etc. represent the terminals of the coils, *1'* and *2'* must be connected together, also *2* and *3*, and so on. The end *8* is connected to the other collector ring and the winding thus completed. The connections of such a winding are quite simple; but if not connected with regard to the direction of the E. M. F.'s, as shown above, the armature will fail to work properly. For example, if *1'* were connected to *2*, *2'* to *3*, and so on around the armature, the even-numbered coils would exactly counterbalance the odd-numbered ones and no voltage would be obtained between the collector rings. Of course, in this case all the coils are supposed to be wound in the same direction, as is nearly always done in practice. The connections shown in the diagram, Fig. 6, are shown between the coils in Fig. 5. It should be noted, in passing, that this constitutes an open-circuit winding; that is, the winding is not closed on itself, like that of a continuous-current drum or ring armature. A large number of alternator windings are of the open-circuit type, which is well adapted for the production of high voltages, because it admits of a large number of turns being connected in series.

**6.** Most alternating-current dynamos of the revolving-armature and stationary-field type are built on much the same lines as direct-current multipolar machines. Usually, however, they have a larger number of poles. Fig. 7 shows a common type of alternator having a revolving armature *a* and a stationary field *f*, with inwardly projecting poles on which are placed the spools *s*. This is an eight-pole machine with an armature winding similar to that shown in the diagram, Fig. 6. The two collector rings *r*, *r'* are seen mounted on the end of the shaft outside the bearing, and are connected to the armature winding by heavily insulated leads that pass through a hole in the shaft. Some machines have the collector rings on the armature side of the bearing, thus avoiding the necessity of bringing the wires through the shaft but making the distance between the centers of the bearings greater.

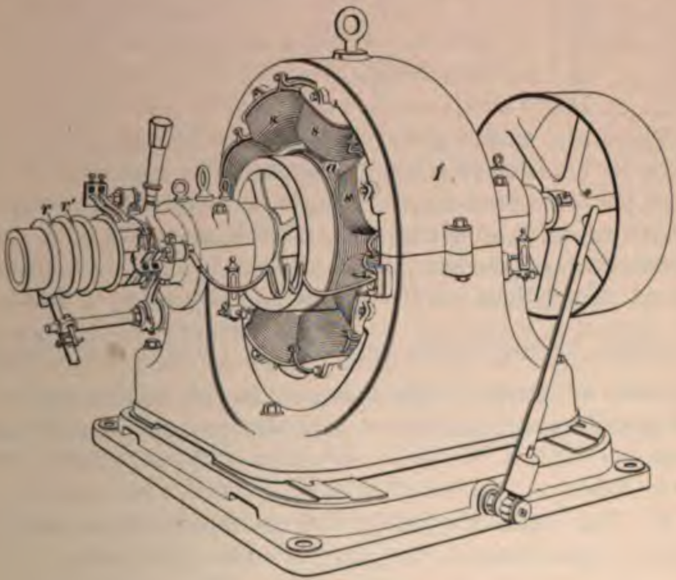

FIG. 7.

**7.** The number of poles on these machines is made large, in order to obtain the necessary frequency without running the machine at too high a speed. It is evident from what has been previously pointed out that for every revolution of the armature, the E. M. F. passes through as many complete cycles as there are pairs of poles, and the frequency will be $n = \frac{p}{2} s$, where $p$ = number of poles and $s$ = revolutions of the armature per second.

We have then,

$$n = \frac{p}{2} \times s;$$

$$s = \frac{2n}{p}. \qquad (2.)$$

Therefore, with a given frequency $n$, the number of poles must be made large if the speed $s$ is to be kept down. For example, if an alternator has eight poles and runs at a speed of 900 revolutions per minute, its frequency will be $\frac{8}{2} \times \frac{900}{60}$ = 60 cycles per second. If we attempt to obtain a frequency of 60, which is a very common one, by using a two-pole machine, its speed must be $s = \frac{2 \times 60}{2}$, or 60 revolutions per second, or 3,600 revolutions per minute, which speed is altogether too high for a machine of any considerable size.

**8.** The distance $e f$, Fig. 8, from the center of one pole piece to the center of the next is called the **pitch** of the alternator. The relation between the pitch and the width of the pole face $A$ varies in different makes of machines, but in a large number of American alternators the distance $B$ between the poles is made equal to the width of the pole face $A$, or $\frac{1}{2}$ the pitch, and the pole pieces cover 50 per cent. of the armature. The shape of the E. M. F. curve is determined largely by the relative shape of the coils and pole pieces and by the way in which the conductors are disposed on the surface of the armature.

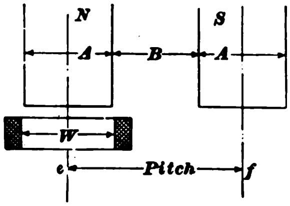

FIG. 8.

**9.** The width of the opening *W* in the coil should not, in general, be much less than the breadth of the pole piece *A*. It has been found that it may be slightly less without doing any harm; but if made too narrow, trouble is likely to arise because the E. M. F.'s induced in different conductors of the same coil are opposed to each other, thus cutting down the total E. M. F. generated.

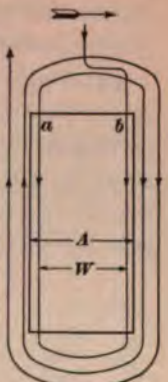

FIG. 9.

This will be seen by referring to Fig. 9, where a coil of three turns is shown with its width of opening *W* less than the polar width *A*. When the coil moves across the pole face in the direction of the arrow, the E. M. F.'s induced in the two conductors *a* and *b* will both be in the same direction, because they both cut lines of force in the same way. The consequence is that these two E. M. F.'s oppose each other, as will be readily seen by following the arrowheads. When an alternator is loaded, the armature reaction causes the magnetism to crowd more or less towards one side of the poles, thus practically reducing the width of the magnetic flux, and on account of this it has been found possible to make the width *W* a little less than *A* without bad results. Usually, however, the width of the opening is nearly equal to that of the pole face.

## FIELD EXCITATION OF ALTERNATORS.

**10.** In most alternating-current systems, the voltage at the points where the current is distributed is kept constant, or nearly so. This means that the voltage at the terminals of the alternator must, as a rule, rise slightly as the load comes on, the amount of rise depending on the loss in the line. At any rate, the voltage at the terminals must not drop off, and, as it has been shown that with a constant field excitation the voltage will fall off with the load, it becomes necessary to increase the strength of the field magnets as the current output of the machine increases. For accomplishing this there are two methods in use, which are analogous to those used for the regulation of shunt-wound and compound-wound continuous-current machines.

**11.** The simplest method is that indicated by the diagram, Fig. 10. *W* represents the armature winding, the terminals *T*, *T'* of which are connected to the collector rings *R*, *R'*, which connect to the line by means of the brushes *g*, *h*. The field is excited by a set of coils on the pole pieces represented by *C*, and current is supplied to these from a small continuous-current dynamo or **exciter** *E*. This is a small shunt-wound machine having an adjustable field rheostat *r* in its shunt field *f*. An adjustable rheostat *R* is placed also in the alternator field circuit. When the voltage drops, the fields may be strengthened by adjusting the resistances *R* and *r*.

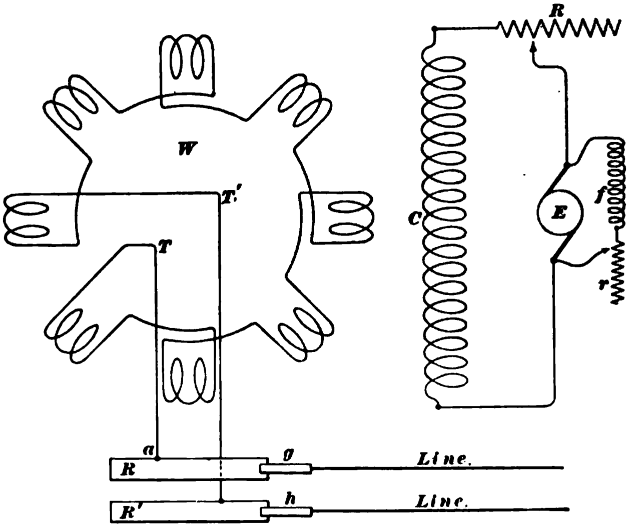

FIG. 10.

**12.** The second method, shown in Fig. 11, varies the excitation of the field in proportion to the current that the machine is supplying, and thus automatically keeps up the voltage. Each field coil in this case consists of two windings similar to those used on compound-wound continuous-current dynamos. One set of windings is separately excited by means of the exciter *E* and is provided with a rheostat *R*, as in the previous case. The field of the exciter is also provided with a rheostat *r*. The greater part of the current furnished by the alternator flows through the series winding

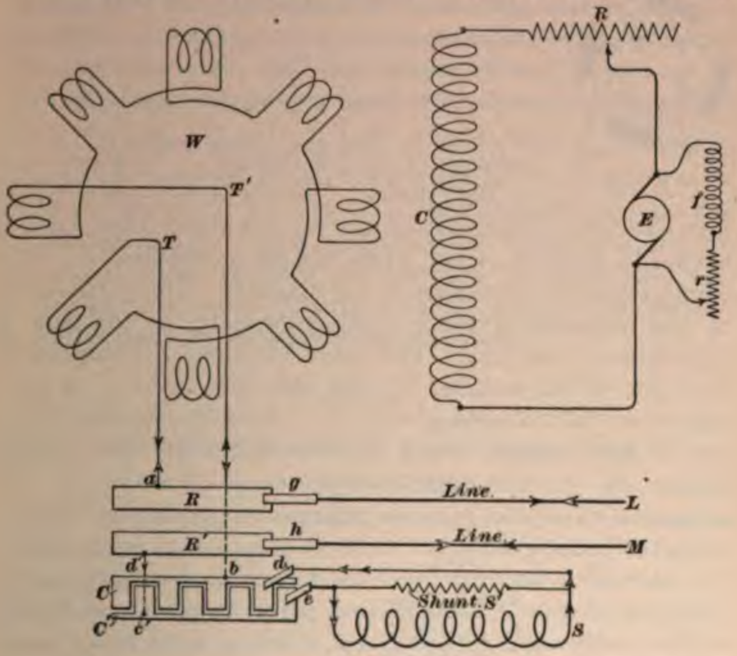

FIG. 11.

represented by the heavy coil *S*; and since this causes the magnetism to increase, the machine maintains its voltage. The separately excited coils set up the magnetism necessary for the generation of the voltage at no load, and the series coils furnish the additional magnetism necessary to supply the voltage to overcome the armature impedance and compensate for the drop in the line.

**13.** The current flowing in these series coils must not be alternating, because if it were it would tend to strengthen the poles one instant and reverse them the next, and on this account the current must be *rectified* before it is sent around the field.

This is accomplished by means of the commutator, or **rectifier,** $C$ $C'$, which is mounted on the shaft alongside the collector rings. It consists of two castings $C$, $C'$ (shown developed in the figure) that are fitted together and form a commutator of as many sections as there are poles in the machine. The alternate sections are connected by the conductors $c$, $c'$, as shown in Fig. 12, the light sections belonging to one casting $C'$ and the dark to the other $C$. Two brushes $d$ and $e$, which press on the commutator, are so arranged that one is always in contact with $C$ while the other touches $C'$. The connections are as shown in the diagram. One terminal $T$ of the armature winding connects directly to the ring $R$ and thence to the line. The other terminal $T'$ connects to one side of the rectifier $C$, and the other side $C'$ is connected to the remaining ring $R'$. By following the direction of the current, it will be seen that while the rectifier causes the current to flow in the same direction in the series coils $S$, it still remains alternating in the line circuit. Take the instant when the coils occupy such a position that the current is flowing from the terminal $T$ and mark the direction of flow in the different parts of the circuit by the closed arrowheads. The current will flow on the line $L$, back on $M$ to $C'$, through $S$, flowing from left to right, back to $C$, and thence back to the armature. When the armature has turned through a distance equal to that between two poles, the current will be flowing in the opposite direction, as indicated by the open arrowheads; that is, it will be flowing out from $T'$ to $C$, from $C$ it will go to the brush $e$ instead of $d$, because it must be remembered that the rectifier has turned through the same angle as the armature, and hence $d$ has slid from $C$ on to $C'$. From $e$ the current flows through $S$ in *the same direction as before* back to $C'$, out on the line $M$, and back on $L$ to $T$. The action of the rectifier is,

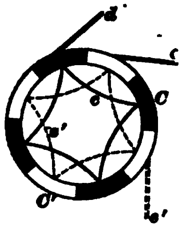

FIG. 12.

briefly, to keep changing the connections of *d* and *e* as the current changes, thus keeping the current in *S* in the same direction while it remains alternating in the line. Usually the brushes *d*, *e* are placed on the commutator as shown by *d* and *e'*, Fig. 12, in order to have them farther apart, their action, however, being the same. A shunt resistance *S'* is usually placed across the coils *S*, in order to adjust the compounding of the machine to suit the circuit on which it is to work, since by varying *S'*, the percentage of the total current passing around the field can be changed.

**14.** Another method is used in which the main current, instead of passing through the rectifier and series coils, flows through the primary of a small transformer carried in the armature. The secondary of this transformer is connected to the rectifier and supplies the series field with a current that varies directly with the load. This method is used largely on Westinghouse machines.

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## REVOLVING-FIELD AND INDUCTOR ALTERNATORS.

**15.** It has been mentioned previously that it makes no difference in the case of an alternator whether the field or armature is the revolving part. It is hardly practicable to make a direct-current dynamo with a revolving field and a stationary armature, because it is necessary that the brushes should always press on the commutator at certain neutral

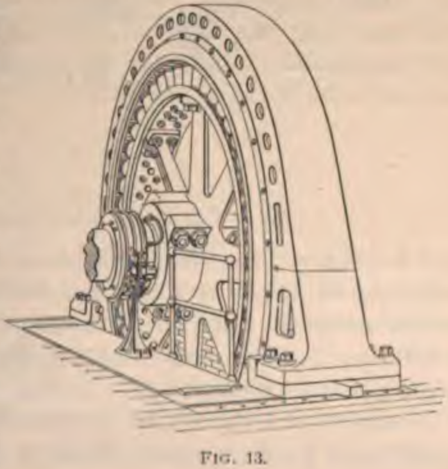

FIG. 13.

points that bear a fixed relation to the field, and the brushes would, therefore, have to revolve with it. This, of course, would be impracticable, because it is often necessary to get at the brushes while the machine is running. In an alternator the brushes pressing on the collector rings do not have to bear any fixed relation to the field, consequently there is no objection to the use of a fixed armature, the current from which can be carried off by leads connected to the winding. Two collector rings are necessary for carrying the exciting current into the revolving field, so that the use of the stationary armature does not do away with moving contacts. The revolving-field type has an advantage in that the armature, being stationary, is easy to insulate for high voltages. This construction also admits of the ready use of armatures of large diameter, thus rendering such machines particularly adapted to slow speeds. Fig. 13 shows a large revolving-field alternator.

**16.** In the inductor type of alternator, the collector rings for supplying current to the field may be done away with and a machine obtained that has no moving contacts whatever. In this class of machine, a mass of iron or **inductor** with projecting poles is revolved past the stationary armature coils. The magnetism is set up by a fixed coil encircling the inductor, and as the iron part revolves the magnetism sweeps over the face of the coils, thus causing an E. M. F. to be set up.

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## TWO-PHASE ALTERNATORS.

**17.** Since a two-phase machine delivers two currents differing in phase by 90°, it follows that the two windings on its armature must be so arranged that when one set is delivering its maximum E. M. F., the E. M. F. of the other set is passing through zero. It has been shown that while the coils move from a point opposite the center of one pole piece to a point opposite the next pole piece *of the same* *polarity*, the E. M. F. passes through one complete cycle; hence, if the E. M. F.'s generated by the two sets of coils are to be displaced 90°, or ¼ cycle, with reference to each other, it follows that one set of coils must be placed one-half the pitch behind the other. This brings one set of conductors under the poles while the other set is midway between them.

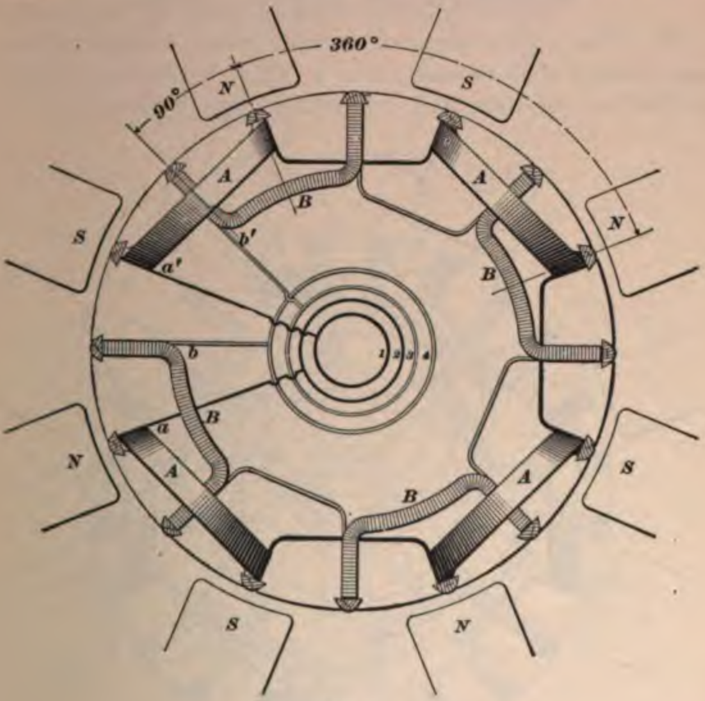

FIG. 14.

Fig. 14 represents a two-phase winding having one group of conductors or one-half a coil per pole per phase. One phase is made up of the four coils *A*, which are connected in series, and the terminals *a*, *a'* brought out to the collector rings *1*, *2*. The four coils *B*, which make up the second phase, are also connected in series, and the terminals *b*, *b'* attached to the light collector rings *3*, *4*. The angular distance by which the center of set *B* is displaced from set *A* is equivalent to 90°, or $\frac{1}{4}$ cycle, as indicated in the figure, the angular distance from *N* to *N* being equivalent to 360°, or one complete cycle.

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## THREE-PHASE ALTERNATORS.

**18.** The requirement of a three-phase armature winding is that it shall furnish three E. M. F.'s differing in phase by 120°, or one-third of a complete cycle. This can be done by furnishing the armature with three sets of windings displaced 120° from each other. This means that phase No. 2 must be one-third the angular distance from one north pole

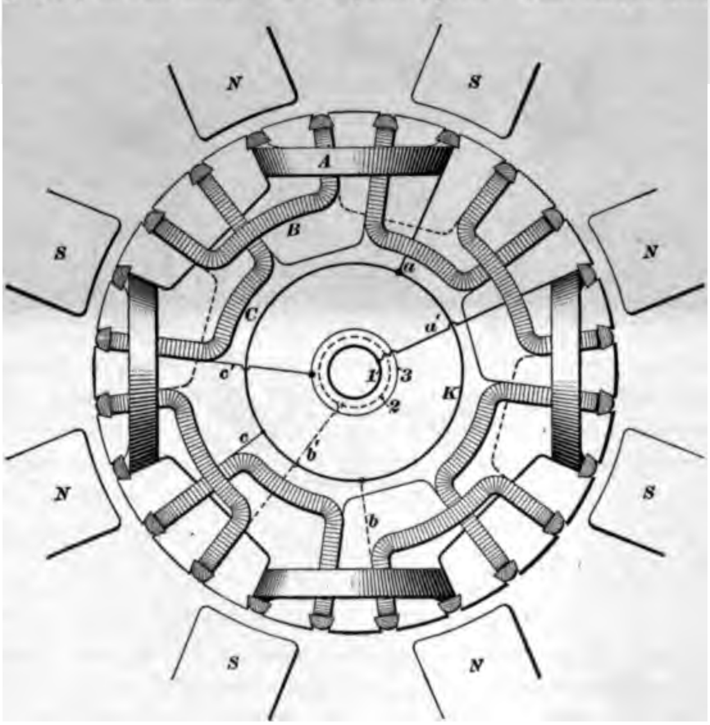

FIG. 15.

to the next north pole behind phase No. 1, and also that phase No. 3 shall be displaced a similar angular distance behind No. 2.

On many actual machines three sets of windings are used that are displaced on the armature a distance equivalent to 60° instead of 120°. One of these windings is, however, reversed so as to make the three E. M. F.'s delivered at the terminals of the machine differ in phase by 120°.

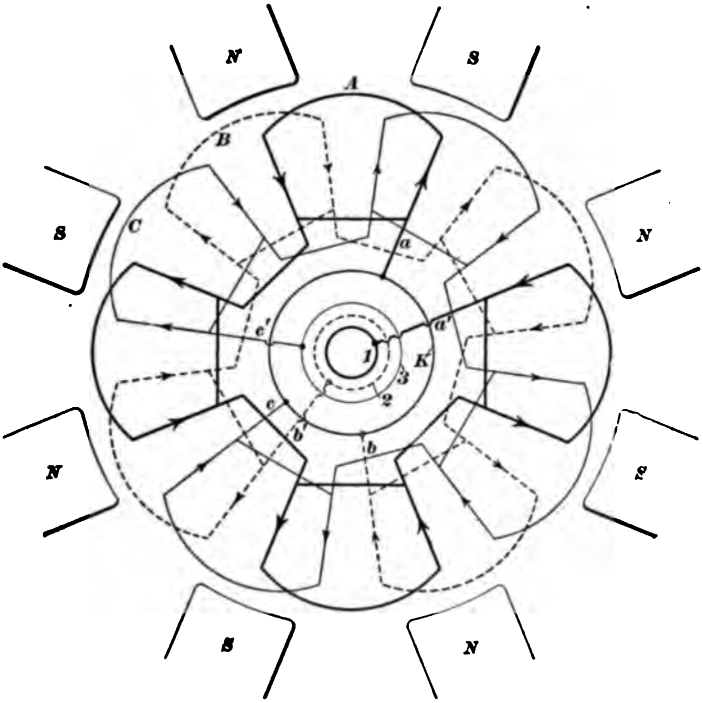

FIG. 16.

**19.** Fig. 15 shows a three-phase winding having one-half coil or one group of conductors per pole per phase. This is the three-phase winding corresponding to the two-phase arrangement shown in Fig. 14. The winding consists of three distinct sets of coils *A*, *B*, and *C*. The angular distance from the center of coil *B* to *A* is equivalent to 120°, or is one-third the distance from *N* to *N*; also the coil *C* is displaced the same distance behind *B*. Each of these three sets is connected in series, leaving the three pairs of terminals *a*, *a'*; *b*, *b'*; *c*, *c'*. The coils are shown diagrammatically in Fig. 16, phase *1* being represented by the heavy lines, phase *2* by the dotted, and phase *3* by the light full lines.

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### STAR AND DELTA CONNECTIONS.

**20.** It has been shown that the three windings of a three-phase alternator can be interconnected so that only three collecting rings will be required. There are two methods by which this may be done. The first is that shown in Fig. 17, and is known as the **Y** or "star" scheme of connection. The coils Fig. 16 are connected according to this plan. One end of each of the windings runs to a common connection *K*, Fig. 17, or, as shown in Fig. 16, the terminals *a*, *b*, *c* all connect to the same common connecting ring. The remaining three ends of the three groups of coils are connected to separate collecting rings.

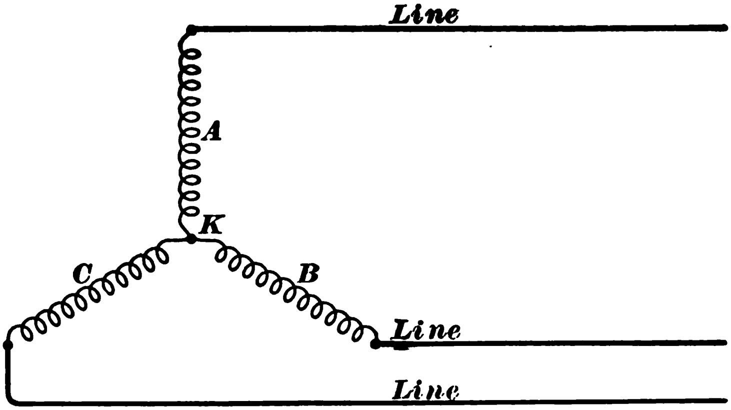

FIG. 17.

The second method of connecting three-phase armatures is known as the △ (delta) or "mesh" method, and is shown in Fig. 18.

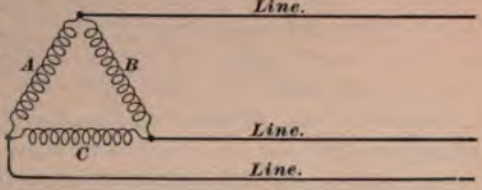

FIG. 18.

Here the three windings *A*, *B*, and *C* are connected together so as to form a closed circuit, and the three collecting rings are connected, one to each of the three points where the windings join one another. Both the **Y** and △ methods of connecting are in common use.

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## MONOCYCLIC ALTERNATOR.

**21.** The monocyclic alternator, brought out by Steinmetz, is intended for use in stations where the greater part of the load consists of electric lights, but where it is also desired to have a machine capable of operating motors as well. In cases where the motor load is large, it is usual to use a regular two-phase or three-phase system.

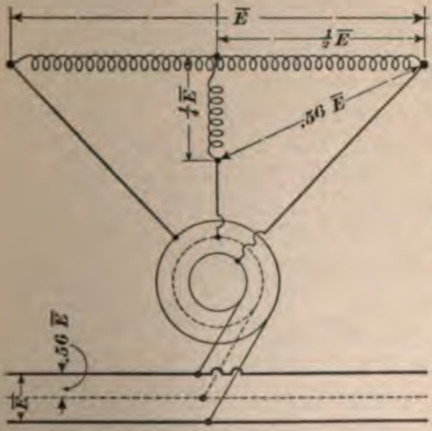

FIG. 19.

The monocyclic alternator is really a single-phase machine having a modified armature winding. The armature is provided with a set of coils constituting the main winding, the terminals of which are connected to the two outside collector rings, Fig. 19. In addition to this winding, a second set of coils is provided, that are placed on the armature 90° behind the main coils, in just the same way as shown for the two-phase machine, Fig. 14. This second set is unlike those in a regular two-phase machine in that the number of turns in the "teaser coils," as they are called, is only one-fourth that of the main set, and one end of the teaser set is attached to the middle of the main winding, instead of being brought out to a collector ring. The other end of the teaser winding is brought to the middle collector ring, as shown in Fig. 19. This second winding furnishes an E. M. F. displaced 90° from the main E. M. F. and of one-quarter its value, thus furnishing an out-of-phase pressure suitable for starting motors. If it is desired to run lights only, the two outside wires alone are used, it being necessary to run the third wire only to places where motors are used. By referring to the figure, it will be seen that the E. M. F. between either of the outside and the middle rings is equal to $\sqrt{(\frac{1}{2}E)^2 + (\frac{1}{4}E)^2} = .56\,E$, nearly. For example, if the main winding generates 1,000 volts, the pressure between the middle and outside rings will be 560 volts, nearly.

**22. Field Excitation of Multiphase and Monocyclic Alternators.**—Multiphase alternators differ very little from single-phase machines as regards their field excitation. Most of the large-size multiphase machines as now built have revolving fields which are separately excited. No rectifiers are used on these machines, and the general tendency seems to be towards discontinuing the use of rectifiers and compound windings, especially on machines of large output. When a compound winding is used on Westinghouse two-phase machines, it is supplied from the secondary of a transformer carried in the armature. This secondary connects to the series winding through the rectifier. The primary of the transformer is provided with two coils, one of which is connected in each phase, so that the current supplied by the secondary is proportional to the loads on the two phases. In the General Electric monocyclic machines, the rectifier and series coils are in series with the main circuit, as already described for single-phase machines. In the case of three-phase machines, the rectifier is frequently connected in one phase only, as the load is usually nearly balanced. In other cases, the rectifier is arranged so that the current of each line flows successively through the series winding.

## TRANSFORMERS.

**23.** One of the principal reasons for the fact that continuous current is giving place so largely to alternating current is the ease with which the latter may be transmitted over long lines at high voltages and then be transformed at the receiving end to currents of lower pressure suitable for operating lights, motors, or other devices. If power is to be transmitted over long distances by means of the electric current, it is absolutely necessary that high line pressures be used in order to make the cost of the conductors reasonably low.

Devices used for changing an alternating current of one voltage to another of a higher or lower voltage are known as **transformers** or **converters.** The first name is the one now generally applied to these devices. Transformers may be used either to "step-up" the voltage, i. e., increase it, or they may be used to "step-down," or decrease, the line pressure. Whether the transformer be used to step up or down, the change in pressure is always accompanied by a corresponding change in the current, and the *power* delivered to the transformer is always a little greater than that obtained from it. For example, suppose a current of 20 amperes were supplied to a transformer from 1,000-volt mains. If the load on the transformer were non-inductive, the E. M. F. and current would be almost exactly in phase, and the watts supplied to the side connected to the mains (*primary* side of the transformer) would be 20 × 1,000, or 20,000 watts. The power obtained from the *secondary* side, or the side connected to the circuit in which the power is being used, would not be quite as much as this.

Suppose the secondary E. M. F. were 100 volts; if there were no losses whatever in the transformation, we would obtain 20,000 watts from the secondary, and the available secondary current would be $\frac{20000}{100} = 200$ amperes. In other words, the decrease in E. M. F. has been accompanied by a corresponding increase in current. As a matter of fact, there is always some loss in conversion, and the secondary output is never quite equal to the power supplied to the primary. The ratio $\frac{\text{watts output}}{\text{watts input}}$ gives the efficiency of the transformer. A good transformer is one of the most efficient pieces of apparatus known, some of large size delivering as much as 98.5 per cent. of the energy supplied.

**24.** Transformers used for changing an alternating current at one pressure to an alternating current at another pressure are often called *static transformers*, because they have no moving parts. This is done to distinguish them from *rotary transformers*, which are used to transform alternating currents into direct currents, or *vice versa*. Such machines always have moving parts, hence their name. Nearly all transformers are operated on constant-potential systems. The transformer is supplied with current from mains, the pressure between which is kept constant, and this current is transformed to one of higher or lower pressure, the secondary pressure also being constant or nearly so.

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## PRINCIPLE OF THE TRANSFORMER.

**25.** A simple transformer is shown in Fig. 20. $C$ is a laminated iron ring on which are two coils $P$ and $S$. The coil $P$ has a certain number of turns $T_p$, and $S$ has, we will suppose, a smaller number of turns $T_s$. The coil $P$ is the primary and is connected to the alternator mains across which the constant pressure $E_p$ is maintained. We will suppose, for the present, that the resistance of both the primary and secondary coils is negligible.

The above is essentially the construction of the ordinary static transformer. It consists of two coils or sets of coils interlinked by an iron magnetic circuit. Of course the forms of different transformers vary widely, but they all contain the three essential parts mentioned.

Suppose a voltmeter $V$ to be connected to the terminals of the secondary coil $S$. The resistance of the voltmeter is very high, consequently a very small current will flow through the secondary coils, and we may, for all practical purposes, consider the secondary coil as an open circuit in which no current is flowing. The line E. M. F. $E_p$ will cause a current to flow through the primary coil, and this current will set up an alternating magnetic flux in the iron core. This alternating flux will set up a counter E. M. F. in the coil $P$, which will be very nearly the equal and opposite of $E_p$.

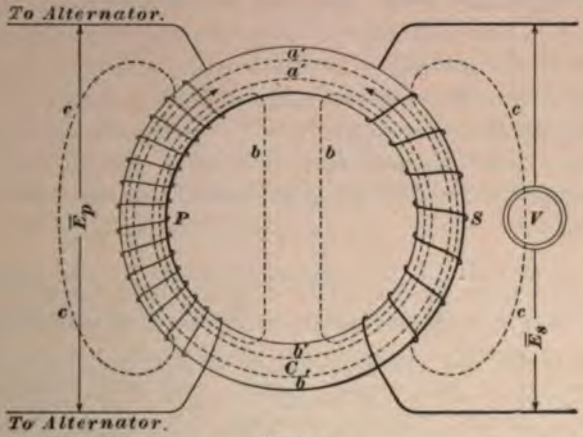

FIG. 20.

The current that will flow, therefore, in the primary coil when the secondary coil is on open circuit is the current that is required to set up a magnetic flux $N$ capable of producing a back E. M. F. equal and opposite to the applied E. M. F. Since the coil $P$ is wound on a closed, iron magnetic circuit, it is evident that a small current in $P$ will be capable of setting up a large amount of magnetism through itself, provided there is no opposing force. The current that flows in the primary coil when the secondary coil is on open circuit is, therefore, very small, because the primary coil has a high self-induction and chokes back the current by virtue of the counter E. M. F. that is set up. The magnetic flux set up in the iron circuit by the coil $P$ passes through the secondary coil $S$ also, and because of the fact that this flux is always changing, an E. M. F. will be set up in the coil $S$ and will be indicated by the voltmeter $V$. The amount of this secondary E. M. F. will depend on the number of turns with which $S$ is wound. If $S$ has fewer turns than $P$, $E_s$ will be less than $E_p$ and the transformer will step down. If $S$ has the same number of turns as $P$, $E_s$ will equal $E_p$. If $S$ has a greater number of turns than $P$, $E_s$ will be greater than $E_p$ and the transformer will step up.

**26.** The ratio of the primary voltage to the secondary at no load, i. e., $\frac{E_p}{E_s}$, is called the **ratio of transformation.** Also the ratio of transformation is equal to the primary turns divided by the secondary turns. For example, if a transformer be supplied with 1,000 volts primary and has 500 turns on its primary coil while there are 50 turns on the secondary, the ratio of transformation is 10 and the secondary voltage $1,000 \times \frac{50}{500} = 100$ volts. In this case the transformer reduces the voltage from 1,000 to 100, but the operation could be reversed, that is, it could be fed with 100 volts and the pressure raised to 1,000.

**27.** It was assumed above that all the magnetic flux $N$ that threaded the primary coil also passed through the secondary, and in well-designed transformers this is very nearly the case. However, some lines may leak across, as shown by the dotted lines $b$, $b$, $c$, $c$, without passing through both coils. This is known as **magnetic leakage.**

If the transformer is poorly designed, this magnetic leakage may become large when the transformer is loaded, and thus cause a falling off in the secondary voltage. The resistance of the primary and secondary coils also causes the secondary voltage to drop off somewhat as the transformer is loaded, because a part of the E. M. F. is required to force the current through the coils against their resistance.

When a load is attached to the secondary, Fig. 20, a current flows through *S*, and this current is opposite in phase to the current in the primary; the secondary, therefore, tends to set up an opposing magnetic flux. The curved arrows in Fig. 20 represent the way in which these two fluxes oppose each other. The effect of the current in the secondary is to cut down the choking effect of the primary and thus allow more current to flow through the primary. As, therefore, the load is applied to the secondary, the current in the primary increases in proportion, and the transformer takes a current from the line that is proportional to the load that the secondary carries.

**28. Transformer Losses.**—The student must remember that no transformer gives out quite as much energy from its secondary as it takes in in its primary. There is always some unavoidable loss. These losses are of two kinds, namely, $C^2 R$, or *copper, loss* and *hysteresis* and *eddy current* or *iron losses*. These are similar to the losses that take place in the armature of a dynamo. **Copper loss** is due to the heating of the coils on account of their resistance and thus increases rapidly as the load increases. The **hysteresis** or **iron loss** is caused by the continual reversal of the magnetism in the iron. The loss due to **eddy currents** in the core can be made very small if the core is carefully laminated. The hysteresis loss can only be kept down by using a very good quality of iron in the core and avoiding high magnetic densities in it.

**29. Regulation.**—If a transformer is supplied with a constant primary pressure, the secondary pressure will also remain nearly the same no matter what the load may be. There will be a slight falling off in voltage from no load to full load, which is due to the resistance of the coils and the fact that there is always some magnetic leakage between the primary and secondary coils; but if the transformer is well designed, this falling off will be slight. The reaction of the secondary coil is such that as the load increases, the primary current also increases, but the secondary voltage remains nearly the same. The primary voltage is, of course, maintained at a constant value by the alternator supplying the current.

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## CONSTRUCTION OF TRANSFORMERS.

**30.** Transformers are made in a variety of forms, but they may, for convenience, be divided into two general classes: (*a*) Core transformers; (*b*) shell transformers.

In the **core transformer,** the iron part forms a core on which the coils are wound, while in the other arrangement the iron surrounds the coils. Figs. 21 and 22 show the arrangement of the parts of a common type of core transformer. The core *C*, Fig. 21, is built up of thin iron strips into the rectangular form shown; *P*, *P'*, *S*, *S'* are the primary and secondary coils, each being wound in two parts. It will be noticed that the primary is wound over the secondary, thus making the

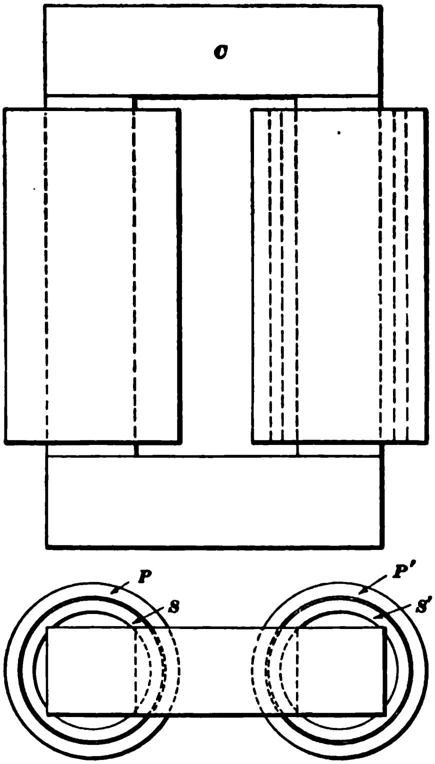

FIG. 21.

leakage path between the coils long and of small cross-section, thereby reducing the magnetic leakage.

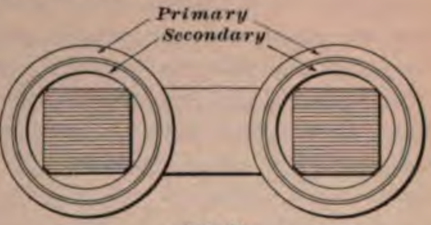

FIG. 22.

Fig. 22 shows a section of the coils and core.

One advantage of this type is that the core may be built up of strips of iron, no special stampings being required. There is also an advantage in having the coils wound in two sections, in that it enables the transformer to be connected for a variety of voltages. For example, suppose each primary coil were wound for 1,000 volts and each secondary for 50 volts. By connecting the primary coils in series or parallel, the transformer could be operated on 2,000- or 1,000-volt mains, and by connecting the secondaries in series or parallel, a secondary voltage of either 100 or 50 could be obtained. Modern transformers are usually built in this way because it is often convenient to be able to make these changes.

**31.** Figs. 23 and 24 show a common type of **shell transformer.** Here the primary and secondary coils $P$, $P_1$ and

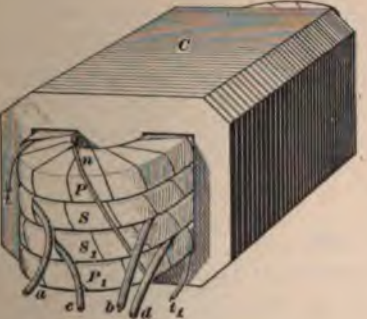

FIG. 23.

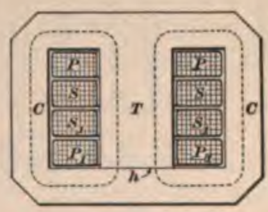

FIG. 24.

$S$, $S_1$, respectively, are surrounded by the iron core $C$, which is built up of iron stampings of the form shown in the sectional view, Fig. 24. A cut is made in the stamping at $h$, so that the tongue $T$ may be bent back to allow the stampings to be slipped over the coils. The magnetic lines are set up around the circuit, as indicated by the dotted lines, and thus pass through both primary and secondary coils. The primary and secondary coils are split into two sections, the primary being divided into two parts and placed on each side of the secondary. The two parts of the primary coils are connected in series by the connection shown at $n$; $t$ and $t_1$ are the primary terminals. The ends $a$ and $b$ of coil $S$ and $c$ and $d$ of coil $S_1$ are brought out separately, in order that the two coils may be connected either in series or in parallel, as may be desired. Leakage tends to take place between the coils, and by interleaving the primary and secondary the leakage is reduced.

**32.** Transformers for outside work are placed in a weather-proof iron case, such as is shown in Fig. 25. This shows a case suitable for a transformer of the style shown in Fig. 21. The wires $a$, $b$ are the primary terminals, and $c$, $d$, $e$, $f$ are connected to the secondary mains. The case in which transformers are placed is often filled with an insulating oil that not only tends to keep the insulation better, but also helps to get rid of the heat by conducting it from the transformer to the iron case, and thence to the outside air.

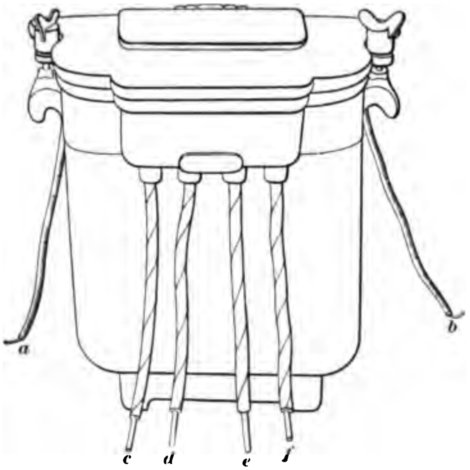

FIG. 25.

The ratio of transformation for transformers used in ordinary lighting work is usually 10 or 20, that is, 1,000 or 2,000 volts primary and from 50 to 200 volts secondary.

**33. Selection of Transformers.**—In selecting transformers for a given lighting or power system, only the best should be obtained, even if the first cost is somewhat higher than those of less reliable make. A poor transformer will waste more power in the course of a few years than it is worth. For example, suppose a transformer has a large core loss. This loss goes on all the time that the pressure is applied to the primary whether the secondary is delivering any current or not, and the cost of this power may amount to a surprisingly large amount in the course of a year. All transformers are bound to have some core loss, but, as a general rule, cheap transformers of a given output have a larger loss than those of a more expensive but more reliable make, because in the latter case greater care is taken in the selection of the iron in the core. Moreover, the core loss is liable to increase greatly the longer the transformer is used, if proper care is not taken in designing the transformer and in selecting the iron. This effect is known as **aging** and appears to be due to changes brought about in the character of the iron by the long-continued heating while the transformer is in action. The only remedy is to take down the transformer core and anneal the sheets. Transformer builders have paid considerable attention to this subject and are now able, by carefully selecting the iron or mild steel used for the core and by designing their transformers to work at a low temperature, to do away largely with this effect.

**34. Insulation Test for Transformers.**—It is extremely important that the insulation of transformers shall be good. If the primary should, in any way, come into contact with the secondary, the high pressure would be applied to the secondary lines and bring about a very dangerous condition of affairs. A number of fatal accidents have occurred that have been traced to defective transformer insulation, and before any transformers are put into service they should be tested to see that their insulation is all right. New transformers are generally tested at the factory, but before any old or second-hand transformers are put into service, they should be subjected to a test by applying a high-pressure alternating current to the windings. Measurements of the insulation resistance by means of a Wheatstone bridge are useless for a test of this kind. Fig. 26 shows the general scheme of connections for a high-potential test as applied to testing the insulation between the primary and secondary coils of the transformer $T$. The high pressure needed for testing is usually obtained from

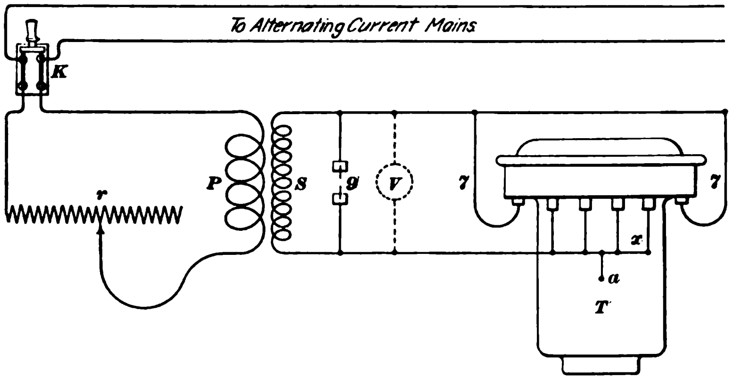

Fig. 26.

a special high-potential, step-up transformer, though if this is not available a number of ordinary transformers may be used with their fine-wire coils connected in series, so as to give the high pressure desired. The main switch $K$ is connected to the primary coil $P$ through an adjustable resistance $r$ that enables the high pressure generated in the secondary $S$ to be regulated. The ends 7, 7 of the primary coil of the transformer under test are connected together and to one end of $S$. The ends $x$ of the secondary coils are also connected together, grounded on the case at $a$, and connected to the other terminal of $S$. It is important that the various terminals of the coils be connected as indicated, otherwise some parts of the winding will be subjected to greater strains than others. When the switch $K$ is thrown in, the high E. M. F. generated in $S$ tends to break down the insulation between the primary and secondary coils of $T$. The applied pressure should be at least three times the primary pressure at which the transformer is designed to work; i. e., a 2,000-volt transformer should stand a pressure of at least 6,000 volts between its primary and secondary coils.

**35.** In order to determine the applied voltage, a spark gap $g$ between needle points or a static high-reading voltmeter $V$ may be used. It has been found by experiment that the voltage required to jump between needle points in air increases almost in direct proportion to the length of the gap, until about 30,000 volts is reached; 30,000 volts (alternating) will jump about 1½ inches in air between bright needle points; 15,000 volts will jump about ¾ inch; 10,000 volts, ½ inch; and so on. By setting the points, say, ½ inch apart and then raising the voltage, by cutting out $r$, until a spark jumps across, it is known that the pressure applied to the transformer is about 10,000 volts. If needle points are used, they should be renewed after every discharge, otherwise they become corroded and give inaccurate results.

**36.** In applying high-potential tests, care must be taken not to permanently strain and injure the insulation. It is all well enough to apply a test that will indicate to a certainty that the insulation will be capable of standing the strain put on it in service, but if the test is made unnecessarily severe, good apparatus may be permanently injured. High-potential tests should not, therefore, be long continued—a few seconds is sufficient to show whether the insulation is defective or not; a longer application will only serve to injure good insulation. High-potential tests should be made when the apparatus is hot, because then the insulation is weaker than when cold, and any weak spots will be more likely to show themselves; besides, the transformer is warm when used under actual operating conditions.

## ALTERNATING-CURRENT MOTORS.

**37.** Motors designed for use in connection with alternating currents may be divided into two classes: (1) Synchronous motors, and (2) induction motors.

Both kinds are in common use, and by far the larger part of all the motors operated in connection with the alternating current belong to one or other of these classes. There are a few other motors that are used to some extent, but their number is insignificant when compared with those of the above two classes.

### SYNCHRONOUS MOTORS.

**38. Synchronous motors** are made to operate either on single-phase or polyphase systems, and are so called because they always run in synchronism with, or at the same frequency as, the alternator driving them. In construction they are almost identical with the corresponding alternator, and always consist of the two essential parts, the field and the armature, either of which may revolve. The field of such motors must be excited from a separate continuous-current machine in the same way as an alternator. The fields of synchronous motors are, however, very seldom compound-wound, and hence no rectifier is required; otherwise, the whole construction of the motor is about the same as that of the alternator.

**39.** If a single-phase alternator be connected to another similar machine, the latter will not start up and run as a motor, because the current is rapidly reversing in its armature, thus tending to make it turn first in one direction and then in the other. The consequence is that the armature does not get started from rest. If, however, the second motor be first run up to such a speed that the frequency of its alternations is the same as that of the alternator, and then connected into circuit, the impulses of current will tend to keep it rotating, and the machine will continue running as a motor. The motor must be run up to synchronism by means of some outside source of power, and the fact that single-phase synchronous motors will not start of their own accord is a serious drawback to their use. On the other hand, polyphase synchronous motors will start from rest and run up to synchronism, but such motors take quite a large current from the line, and they will not start at all under any heavy load. They must, therefore, be started first and the load applied afterwards, when they will continue running in synchronism with the alternator and will take current from the line in proportion to the work done. Large synchronous motors are often started by means of a small induction motor that is thrown out of use after the large machine has been brought up to synchronism. Single-phase synchronous motors are now seldom used.

**40.** Synchronous motors behave differently in some respects from direct-current machines. If the field of a direct-current motor be weakened, the motor will speed up in order to maintain the proper value of the counter E. M. F. If the field strength of a synchronous motor be changed, the speed cannot change, because the motor must keep in step with the alternator. Such a motor adjusts itself to changes of load and field strength by the changing of the phase difference between the current and E. M. F.

Imagine a synchronous motor that runs perfectly free when not under load. If this machine were run up to synchronism and its field adjusted so that the counter E. M. F. of the motor were equal and opposite to that of the dynamo, no current would flow in the circuit when the two were connected. At any instant the E. M. F. that causes current to flow is the difference between the instantaneous E. M. F. of the alternator and the counter E. M. F. of the motor. If the motor be loaded, its armature will lag a small fraction of a revolution behind that of the alternator and the motor E. M. F. will no longer be in opposition to that of the alternator, consequently a current will flow that is sufficiently large to enable the motor to carry its load. The greater the load applied, the larger will be the current that is thus allowed to flow.

It must be borne in mind that this phase difference is caused by a small relative lagging of one armature behind the other, not by a difference in speed. For example, the change of phase from full load to no load might not be more than 25°, and this would mean an angular displacement on the machine of a little more than one-fourth a pole face. If the machine be loaded too heavily, the slipping of the motor armature will become sufficiently great to throw the motor out of synchronism, and it will come to a standstill.

**41.** Since polyphase synchronous motors will, when not loaded, run up to synchronism of their own accord, they are largely used for power-transmission purposes in places where a large starting effort is not required and where the motor is not started and stopped frequently. They have an advantage over induction motors in that they do not produce lagging currents, and are therefore better adapted for power-transmission plants. What was said with regard to alternator armature windings also applies to synchronous motors, such motors being built for either two-phase or three-phase systems.

**42.** The speed at which a synchronous motor will run when connected to an alternator of frequency $n$ is $s = \frac{2n}{p}$, where $s$ is the speed in revolutions per second and $p$ the number of poles on the motor. For example, if a 10-pole motor were run from a 125-cycle alternator, the speed of the motor would be $\frac{2 \times 125}{10} = 25$ revolutions per second, or 1,500 R. P. M. It follows from the above that if the motor had the same number of poles as the alternator, it would run at exactly the same speed, and any variation in the speed of the alternator would be accompanied by a corresponding change in the speed of the motor.

## INDUCTION MOTORS.

**43.** In a great many cases it is necessary to have an alternating-current motor that will not only start up of its own accord, but one that will start with a strong torque. This is a necessity in all cases where the motor must start up under load. It is also necessary that the motor be such that it may be started and stopped frequently, and, in general, that it may be used in the same way as a direct-current motor. These requirements are fulfilled by *induction motors.*

**44. Induction motors** are usually made for operation on two-phase or three-phase circuits, although they are sometimes operated on single-phase circuits by using special starting devices. They consist of two essential parts, namely, the *primary*, or field, to which the line is connected, and the *secondary*, or armature, in which currents are induced by the primary. Either of these parts may be the revolving member, but we will suppose in the following that the field is stationary and that the armature revolves. In a synchronous motor or direct-current motor, the current is led into the armature from the line, and these currents, reacting upon a fixed field provided by the stationary field magnet, produce the motion. In the induction motor, however, two or more currents differing in phase are led into the field, thus producing a magnetic field that is constantly changing and that *induces* currents in the coils of the armature in the same way that currents are induced in the secondary coils of transformers. These induced currents react on the field and produce the motion of the armature. It is on account of this action that these machines are called induction motors.

## FIELD WINDING.

**45.** The winding on the field of an induction motor is almost exactly the same as that on the armature of a synchronous motor or polyphase alternator. The field structure is built up of disks having teeth on their inner circumference that form slots when the core is assembled. The coils are placed in these slots, forming a winding like that on the surface of a polyphase armature. The winding, when completed, resembles very much the evenly distributed arrangement of

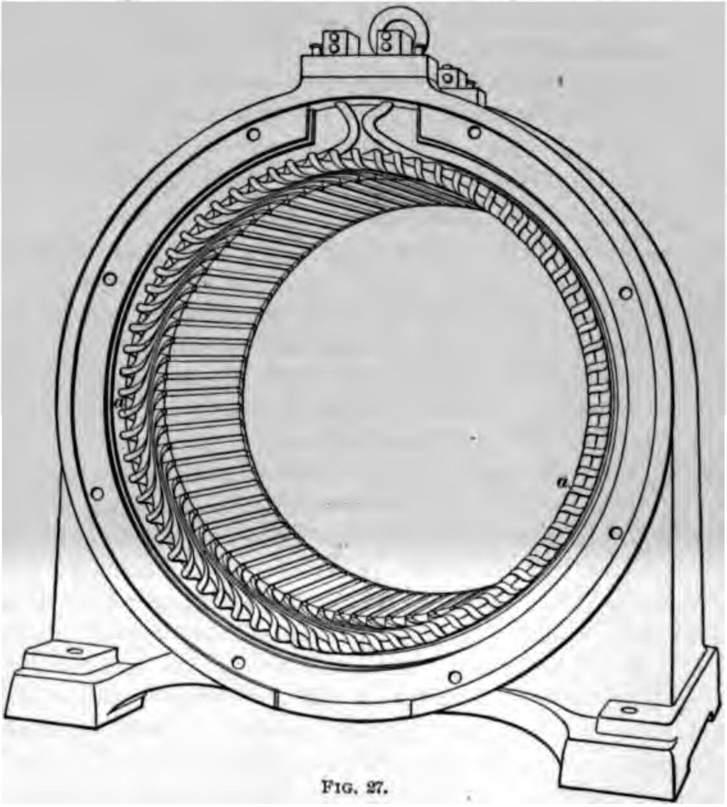

FIG. 27.

coils on a continuous-current armature. Fig. 27 shows a finished field for an induction motor. The coils are seen at *a*, *a* distributed evenly around the inner circumference.

### ACTION OF INDUCTION MOTOR.

**46.** In order to understand the action of an induction motor, it will help matters to compare it briefly with the action of an ordinary direct-current motor. Suppose we have a four-pole direct-current armature surrounded by its field. If the field is excited and current sent into the armature through the brushes in the ordinary way, the armature will revolve; and the greater the load placed on the machine, the more current will it take to drive the armature. Suppose that instead of driving the armature in this way we remove the brushes and press a copper ring over the commutator so as to connect all the bars together. This will connect all the ends of the armature coils together, making them form a number of closed circuits. Also, suppose that we revolve the field around the armature instead of having it stand still, as is usually the case, and that the armature be held from turning. The lines of force from the field will cut across the armature conductors and set up E. M. F.'s in them. Since the coils are all short-circuited by the rings on the commutator, the result is that heavy currents are set up, and these currents reacting on the field produce a powerful dragging action on the armature. If, therefore, the armature is released, it will be dragged around after the field. If the armature revolved at exactly the same speed as the field, the conductors would move around just as fast as the lines of force; no E. M. F.'s would be set up in the armature conductors and no turning effort or torque would result. It follows, then, that the armature must always revolve a little slower than the field, in order that any drag may be exerted. It should be noticed that in this arrangement no current is led into the armature from outside; it is *induced* in the armature by the revolving field.

The field in this case is supposed to be excited by continuous current and is revolved by mechanical means; but by using two or three alternating currents displaced in phase, we can make the magnetism sweep around the armature without actually revolving the field frame itself. In other words, we can set up magnetic poles that will be continually shifting around the armature without actually revolving the field structure. Fig. 28 will show how this is carried out by using two currents differing in phase. *F* is the field frame, having, in this case, eight polar projections (four for each phase), on each of which is wound a coil. Coils No. *2*, *4*, *6*, and *8* are connected in series, every other coil being reversed as shown. The terminals *b*, *b'* of this series of coils are connected to phase No. *2* of the alternator. The other four coils are joined in the same way and are connected to terminals *a*, *a'* of phase No. *1*. The current in each of these phases is constantly changing, and when the current in one phase is

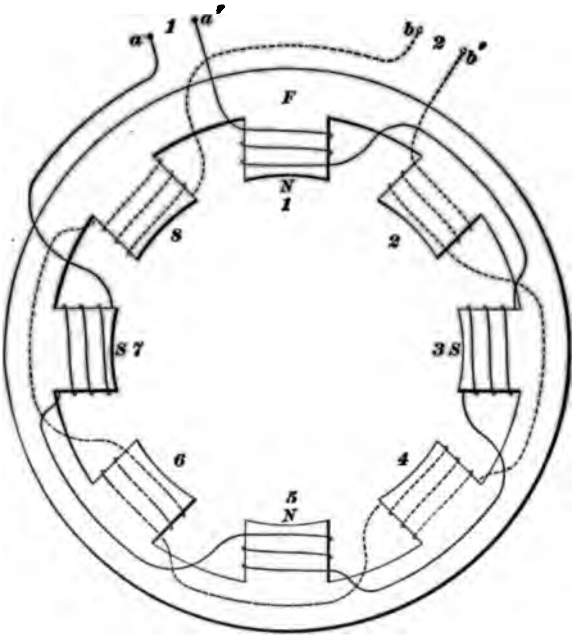

FIG. 28.

at its maximum, the current in the other phase is zero. Suppose that we consider the instant when the current in phase No. *1* is a maximum; the current in phase No. *2* at the same instant will be zero and there will be no magnetism in poles *2*, *4*, *6*, or *8*. Suppose the current is flowing in such a direction in phase No. *1* that a north pole is formed at *1*, then there will be a south pole at *3*, a north pole at *5* and a south pole at *7*. After one-quarter of a cycle has passed, the current in phase No. *1* will be zero and the current in phase

No. *2* will have increased to its maximum value; there will then be no magnetism in poles *1*, *3*, *5*, and *7*, and we will have a north pole at *2*, a south pole at *4*, and so on. At the end of the next quarter cycle the current in phase No. *1* will again be at its maximum value, but will be flowing in the opposite direction to what it did before. We will then have a south pole at *1*, a north pole at *3*, and so on. The result of these changes is that the poles keep shifting around, and we have practically the same effect as if we had a four-pole field structure actually revolving. Of course the current in the coils does not change suddenly, but the magnetism in the poles dies away and increases as the current changes.

The style of field generally used is shown in Fig. 27. The principle is the same as that shown in Fig. 28, but the winding is split up into a large number of small coils placed in slots instead of using a few coils on projecting poles.

**47.** Fig. 29 shows the type of armature commonly used. It is extremely simple in construction and consists of a laminated iron core provided with slots, in each of which is placed a heavy copper conductor *b*. These conductors project at each end of the core and are bolted to the copper rings *r*, *r* that connect all the bars together and thus form a number of closed circuits. An arrangement of this kind is often referred to as a "squirrel-cage" armature, because the conductors and end rings resemble a squirrel cage.

When such an armature is placed in the field shown in Fig. 27 and the current turned on, the magnetic field sweeps around the armature and cuts the bars and sets up currents in the closed circuits formed by the bars and the end rings. There is a powerful drag exerted on the armature, and it is very soon brought up to such a speed that the torque produced by the current in the armature is just sufficient to enable the machine to carry the load. If a heavier load is applied, the speed of the armature drops a little, and thus makes the relative cutting of the lines of force between the armature and field greater, or the *slip* between the armature and field becomes greater. The difference in speed between the revolving armature and the revolving field of an induction motor is known as the **slip**. The slip is usually expressed as a percentage of the speed that the motor would run at when in synchronism with the dynamo. For example, if the synchronous speed of an induction motor were 900 R. P. M., and if the slip were 2 per cent. at full load, the armature at full load would run 18 R. P. M. slower than the revolving field, and the full-load speed of the motor would be 882 R. P. M. This increases the E. M. F. in the armature, causes more current to flow, and thus increases the torque to the amount necessary to carry the load. The motor, therefore, adjusts itself to changes in load by a slight dropping in speed, just as in the case of an ordinary shunt-wound continuous-current motor.

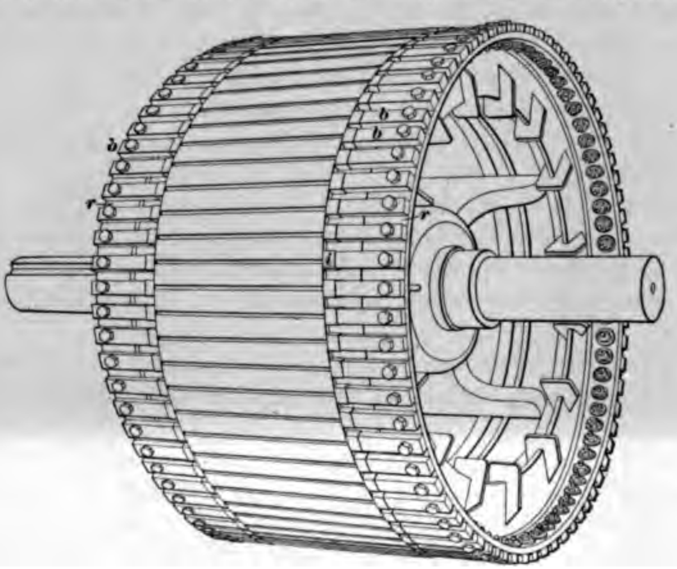

FIG. 29.

**48. Starting Resistance.**—For some kinds of work requiring large starting torque, it is best to have the armature winding so arranged that a resistance may be inserted in series with it while the motor is starting up and cut out when full speed is attained. If this is not done, there will be a large rush of current at starting, because, when the motor is standing still it is in the condition of a transformer with its secondary short-circuited, and since the armature is stationary with regard to the field, a fairly high E. M. F. might be induced, thus causing a very heavy current to flow through the low-resistance secondary winding.

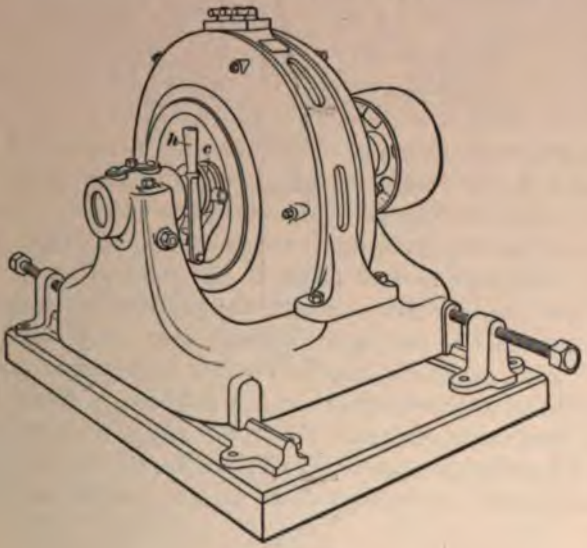

FIG. 30.

This would cause a large current to flow in the primary, and would, therefore, be objectionable. Moreover, this large secondary current so reacts on the field produced by the primary as to greatly weaken it and results in a very small starting torque. If the armature were so designed as to have a fairly high resistance in itself, in order to limit the starting current and procure a good starting torque, the motor would be inefficient and would give bad speed regulation. It is therefore best to have a resistance that may be placed temporarily in the circuit and then cut out.

This may be done by supplying the secondary with a regular winding similar to that of the field and bringing the terminals to collector rings. By means of these rings, connection may be made to a resistance box and resistance cut in or out in much the same way as is done in starting up direct-current motors. In the General Electric Company's motors, the use of collector rings is avoided by mounting the resistance on the armature spider and cutting it out by a switch operated by a sliding collar on the shaft. This enables the motor to be built without any moving contacts whatever. Fig. 30 shows an induction motor of this kind. In this case the sliding collar *c* is operated by the handle *h*. When the speed of an induction motor has to be varied, it is customary to provide the armature with a regular **Y** winding and collector rings, so that an adjustable resistance may be inserted in each phase of the armature winding. Another method of speed regulation is to insert an adjustable resistance or reactance in each phase of the field winding. This avoids the use of collector rings, but the first method is the better and is the one most largely used. Unless a large torque with moderate line current is required at starting, the ordinary squirrel-cage type of armature is used, as it is simpler and cheaper than the type using resistance. By using a starting compensator with a squirrel-cage armature, the line current can be kept down to a reasonable amount.

## ROTARY CONVERTERS.

**49.** It is often necessary to change direct currents to alternating and *vice versa*, and machines for accomplishing this are known as **rotary converters.** The transformation might be effected by having an alternating-current motor coupled to a direct-current generator, simply using the alternating current to drive the motor. An arrangement of two machines is, however, not usually necessary, although such motor-generator sets are used to some extent. Rotary converters are largely used for changing alternating currents to direct for the operation of street railways, electrolytic plants, etc. These machines are often called *rotary transformers*, but the term *converter* is now most generally applied.

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### SINGLE-PHASE CONVERTERS.

**50.** Suppose an ordinary ring armature to be revolved in a two-pole field as shown in Fig. 31; a continuous E. M. F. will be generated and a continuous current obtained by attaching a circuit to the brushes *a*, *a'*. If, instead of the commutator, two collector rings were attached to opposite points of the winding, an alternating current would be obtained in a circuit connected to *b*, *b'*. If the machine be equipped with both commutator and collector rings, the armature may be revolved by means of a direct current led in at the brushes *a*, *a'*, thus running it as a motor instead of its being driven by a belt. The conductors on the revolving armature will be cutting lines of force just as much as

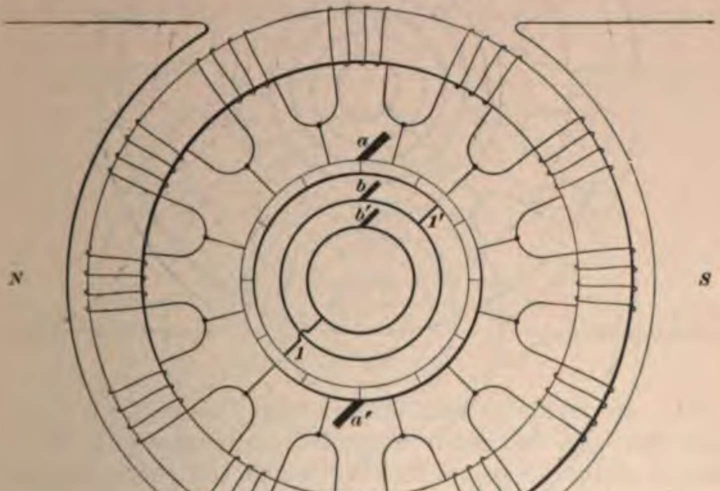

FIG. 31.

they were when the machine was driven by a belt, therefore an alternating current will be obtained from the rings *b*, *b'*. In other words, the machine acts as a converter, changing the direct current into a single-phase alternating current. If the operation be reversed and the machine run as a synchronous alternating-current motor, the alternating current will be transformed to direct current.

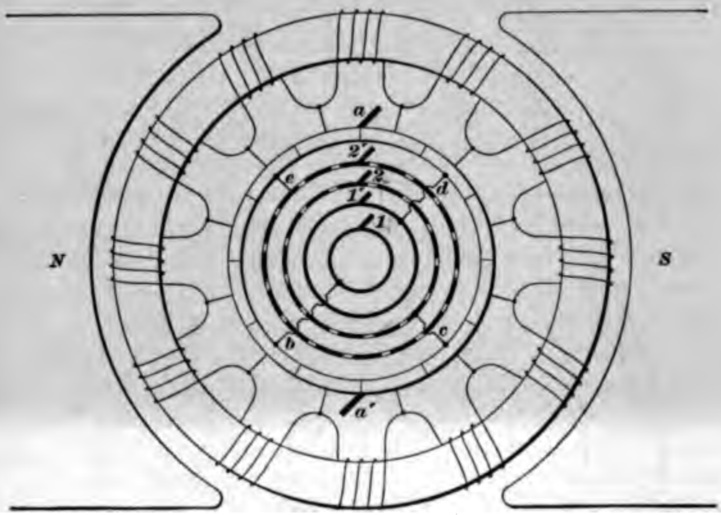

FIG. 32.

**51.** In the above single-phase rotary converter it is evident that the maximum value of the alternating E. M. F. occurs when the points *1*, *1'* to which the rings are connected are directly under the brushes *a*, *a'*; that is, the maximum value of the alternating E. M. F. is equal to the continuous E. M. F. For example, if the continuous E. M. F. were 100 volts, the *effective* volts on the alternating-current side would be $\frac{100}{\sqrt{2}} = 70.7$ volts. Therefore, if $E$ is the alternating voltage and $V$ the direct, we may write for a single-phase rotary converter

$$E = .707\ V. \qquad \textbf{(3.)}$$

### TWO-PHASE CONVERTERS.

**52.** By connecting four equidistant points of the winding *b*, *c*, *d*, and *e*, Fig. 32, to four collector rings, we would have a two-pole two-phase, or quarter-phase, converter. In this case we would have two pairs of lines leading from the brushes *1*, *1*′, *2*, *2*′, and the E. M. F. between *1* and *1*′ or between *2* and *2*′ would be given by formula **3.**

### THREE-PHASE CONVERTERS.

**53.** By connecting three equidistant points as shown at *b*, *c*, and *d*, Fig. 33, a three-phase converter is obtained.

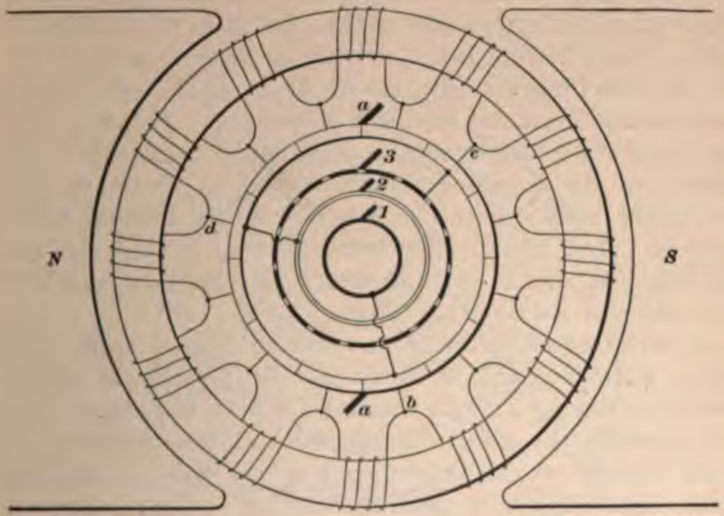

FIG. 33.

Since all direct-current armatures have closed-circuit windings, it follows that the connections on the alternating-current side of a three-phase rotary converter are always Δ, the **Y** connection not being possible. If $E$ be the effective voltage between the lines on the alternating side of a three-phase rotary converter and $V$ the voltage of the continuous-current side,

$$E = .612\ V. \qquad (4.)$$

If such a converter were supplied with a direct current at 100 volts pressure, an alternating current at 61.2 volts would be obtained; and if it were desired to obtain a 100-volt direct current from an alternating current, the alternating side would have to be supplied at a pressure of 61.2 volts.

**54.** Rotary converters are nearly always of the two-phase or three-phase types and are used for changing alternating currents to direct currents. A multiphase rotary used in this way runs as a synchronous motor, hence its speed is practically constant. The student should note that in the rotary converters just shown, the ratio of transformation is fixed, and in order to raise or lower the E. M. F. of the direct-current side, the E. M. F. of the alternating-current side must also be raised or lowered. This is usually accomplished either by means of potential regulators or by providing the transformers which supply the rotary with secondary coils split up into a number of sections which may be cut in or out. The direct-current voltage can also be changed within certain limits by changing the field excitation of the rotary.

If ratios of transformation differing greatly from those given were required, it would not be possible to use an armature having a single winding for both the alternating-current and the direct-current sides of the machine. In such cases, it would be necessary to use either a machine with two distinct armature windings or else a motor-generator set. It is, however, usually possible to get any desired direct E. M. F. from the alternating by transforming the alternating current to such a voltage that when delivered to the rotary transformer, it will be changed to a direct current of the desired pressure. For example, suppose it were desired to transform alternating current at 2,000 volts to direct current at 500 volts suitable for operating a street railway. We will suppose that a three-phase rotary transformer is used. Then it follows from formula **3** that the alternating current must be supplied to the machine at a pressure of $E = .612\ V = .612 \times 500 = 306$ volts. The alternating current would, therefore, be first sent through static transformers so wound as to reduce the pressure from 2,000 to 306 volts, and the secondary coils of these transformers would be connected to the alternating-current side of the rotary.

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### MULTIPOLAR ROTARY CONVERTERS.

**55.** The windings shown in Figs. 31, 32, and 33 give the connections for two-pole machines, but rotary converters

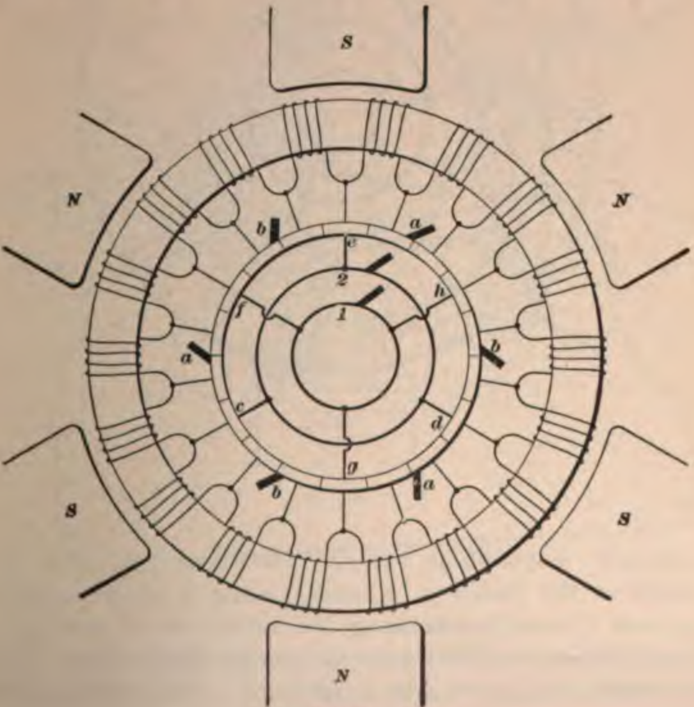


Fig. 34.

**are nearly always made multipolar in order to reduce the speed of rotation. In the single-phase machine shown in Fig. 31, it was necessary to have only one connection to each ring; in a multipolar machine it is necessary to have as many connections to each ring as there are pairs of poles on the machine. Fig. 34 shows the connections for**

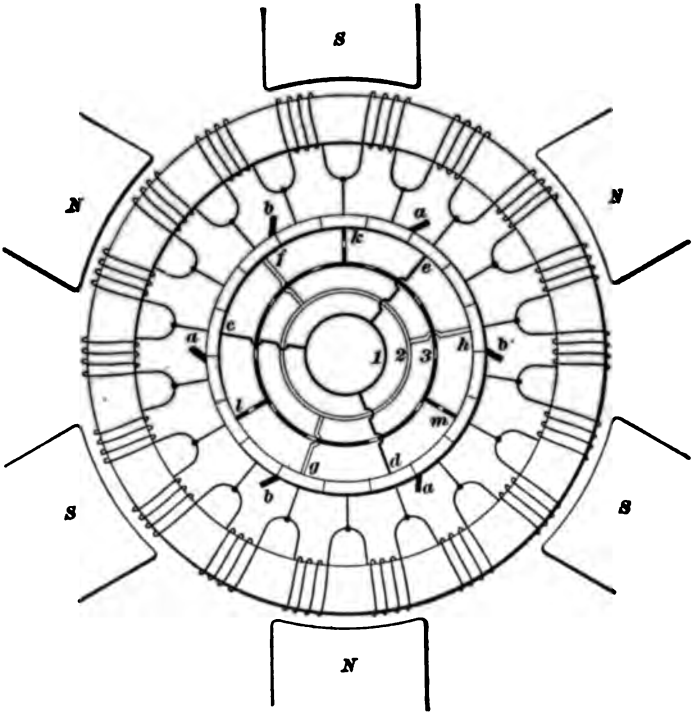


FIG. 35.

a six-pole single-phase rotary. Here the ring *1* is connected to the points *g*, *h*, and *f*, while *2* is connected at *c*, *d*, and *e*, these points being the equivalent of 180° apart. If only two connections were made, as in Fig. 31, the whole of the winding would not be utilized. Fig. 35 represents the same armature connected up as a three-phase rotary.

Here each of the three rings has three connections, as before, and these connections are the equivalent of 120° apart. For example, the angular distance from *k* to *e* is one-third the distance from north pole to north pole, which represents 360 degrees. Such a winding would, therefore, have the three connections *c*, *d*, *e* for ring *1*; *f*, *g*, *h* for ring *2*; and *k*, *l*, *m* for ring *3*, there being *as many connections for each ring as there are pairs of poles.*

**56.** Fig. 36 shows the construction of a modern three-phase rotary converter. The three collector rings are seen at the left-hand end of the machine and the commutator is shown at the right. Like alternators, rotary converters are built for a large range of output and frequency.

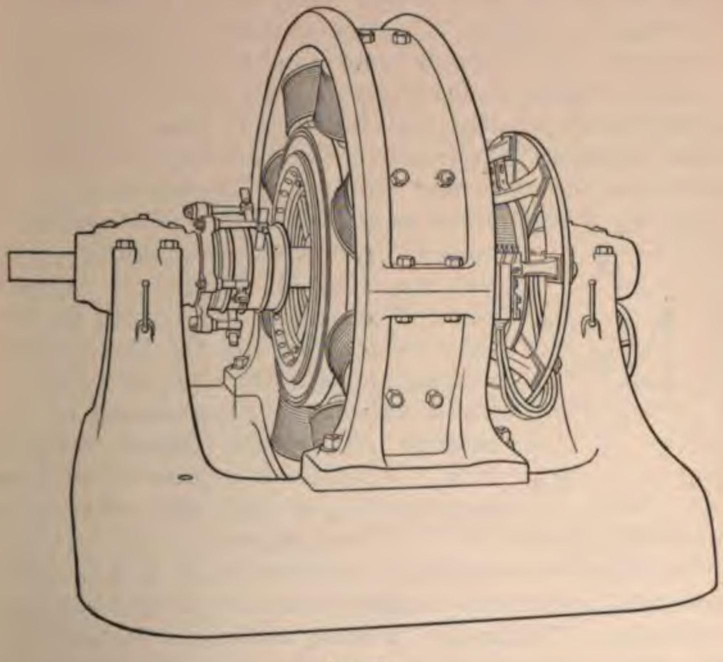


FIG. 36.

## ALTERNATORS WITH CLOSED-CIRCUIT ARMATURES.

**57.** In all that has been said relating to armature windings for alternators we have considered the open-circuit style of winding only. This style of winding, as already pointed out, is used more than the closed-circuit type, because it allows the generation of a higher E. M. F. than the latter with a given number of armature conductors. Alternators are, however, frequently provided with closed-circuit windings. For example, the rotary converter, outside of the addition of the commutator, is practically an alternator and could be run as such. This machine has a closed-circuit winding, the same as a continuous-current dynamo, and a number of taps are simply brought out to the collector rings.

In these machines the armature is provided with a regular closed-circuit winding that is generally about the same as those described in connection with armature windings for multipolar direct-current dynamos. Instead, however, of attaching a commutator as there described, the winding is tapped at two or more equidistant points and the terminals brought to collector rings. For example, in Fig. 37 the circle *1*–*2*–*3*–*4* represents the closed-circuit winding tapped at the four points *1*, *2*, *3*, *4*. The terminals *1'*, *3'*, *2'*, *4'* connect to four collector rings. The current obtained from *1'*, *3'* will differ in phase by 90° from that in *2'*, *4'*, so that this arrangement would be suitable for a two-phase alternator.

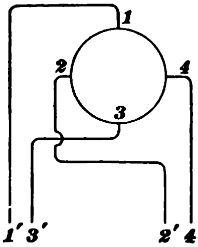
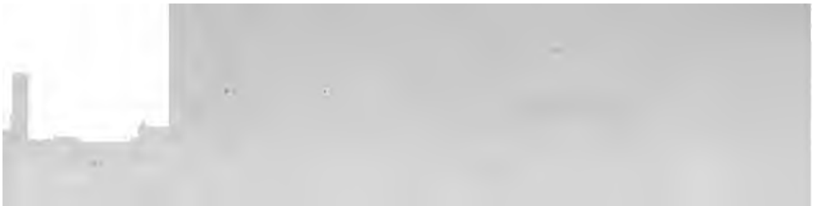


FIG. 37.

In Fig. 37 the winding is supposed to be used in a two-pole field, so that the tapping points are at right angles to each other. The style of winding and connection shown in Fig. 37 is one that has been used very extensively by the Westinghouse Company for their two-phase alternators. If it is desired to operate a two-phase three-wire system from such a machine, three of the collector rings, or taps, are used, as, for example, *1'*, *3'*, *2'*. It is evident that no two of the taps could be connected together without short-circuiting a portion of the armature. If a three-wire two-phase system were operated from lines *1'*, *3'*, *2'*, one phase would be between *1'* and *2'* and the other between *3'* and *2'*. Also, if the E. M. F. between *1'* and *3'*, i. e., the E. M. F. per phase with the four-wire arrangement were $E$, then the E. M. F. between *1'* and *2'*, or the E. M. F. per phase in the second case, would be $\frac{E}{1.414}$. If a three-phase two-pole machine were required, the closed-circuit winding would be tapped at three equidistant points.



# ELECTRIC TRANSMISSION.

## (PART 1.)

## INTRODUCTORY.

**1. Electric transmission** may be defined as the transferring of power from one point to another by means of electricity. The power so transmitted may be used for any of the numerous applications to which electricity is now adapted, such as operating motors, lights, electrolytic plants, etc. The distance over which the power is transmitted may vary from a few feet, as in factories, to several miles, as in some of the modern long-distance transmission plants.

**2.** A power-transmission system consists of three essential parts: (*a*) The station containing the necessary dynamos and prime movers for generating the electricity; (*b*) the line for carrying the current to the distant point; and (*c*) the various receiving devices by means of which the power is utilized.

**3.** Electric transmission may be carried out either by using the direct current, the alternating current, or a combination of the two. Generally speaking, in cases where the transmission is fairly short, the direct current is used. When the distance is long, it is best to use the alternating current. In cases where the distance is long and where alternating current is not well adapted to the operation of the receiving devices, the current transmitted over the line is alternating, and this current is changed to direct current at the distant end and there distributed, thus forming a

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combination of the two systems. The special applications of electric transmission to railway and lighting work will be taken up later in connection with those branches of the subject; for the present, the object is only to bring out a few important points relating to the subject of electric-power transmission generally. Practically, all electric-power-transmission plants, whether direct or alternating, use constant-potential dynamos, i. e., the dynamos in the power station maintain a nearly constant pressure and the current varies with the load.

**4.** Power transmission is extensively used in connection with water-powers that would in many cases be of little use on account of their being located away from railways or commercial centers. It is also coming into use largely in factories to replace long lines of shafting and numerous belts, which are wasteful of power. Its most extensive use, however, is in connection with the operation of street railways, where the power is transmitted from the central station to the cars scattered over the line. The style of apparatus used will depend altogether on the special kind of work that the plant is to do, and the type best adapted for a given service will be taken up when the different transmission systems are treated later.

## THE POWER STATION.

**5.** The **power station** is a building intended for the reception of all the apparatus necessary for the economical and reliable generation of power and its transformation into electric energy for transmission to the points where it is to be used. It is usual, where ground is not expensive, to build a one-story structure, providing room for offices, stores, machinery, etc., or a separate building may be erected for offices and stores.

**6. Prime Movers.**—At present there are three kinds of prime movers in common use for electric-power-transmission work. These are **steam engines, waterwheels,** and **gas or oil engines.** Steam is used more as a source of power than either water or gas, but the development of long-distance power transmission has greatly increased the use of water-power, and the gas engine is rapidly gaining in favor.

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## STEAM PLANTS.

**7. Engines.**—The type of engine that is most suitable for a power station depends entirely on the size of the system and on the general requirements of the service. The closest speed regulation under widely varying loads is obtained with high-speed, automatic cut-off engines, and this class is, therefore, particularly suitable for small electric railways and lighting plants. A little consideration will show that such systems may furnish extremes of load at very short intervals; for if there were on a small railroad only one car in service, the station load would be zero (or simply the friction of the moving machinery) when the car was at rest and a maximum when it was starting on a heavy grade. Again, in a small lighting plant, a large proportion of the lamps may be turned on or off at once, thus causing great fluctuations in the central-station load. In general it may be stated that the larger the system, the nearer will the load approach a constant normal value. In very large systems the load will be a maximum at certain hours of the day or night, and will gradually fall to a minimum at other hours. For such an installation, it is best to use low-speed Corliss engines and run them with condensers, if water for this purpose is readily available. In large plants it is now customary to use large, low-speed Corliss engines, either of the horizontal or vertical type, the latter being preferable where the floor space is limited.

**8. Boilers.**—The boilers in most general use are those carrying the water in tubes and called water-tube boilers, the reason for the preference being that they steam rapidly and will therefore respond quickly to extra demands made upon them. Many stations are, nevertheless, equipped with return-tubular boilers, which give entire satisfaction. For steady work, this type is preferred by many station managers, as the steam pressure in a water-tube boiler will fall as easily as it rises, if the boiler is not properly fired; on the score of safety, however, water-tube boilers are doubtless superior. When space is very limited, vertical boilers are sometimes put in.

Mechanical stokers are much used when it is desired to burn fine coal, and in such cases generally prove economical; also, economizers may be placed in the chimney, close to the boilers, their function being to warm the feedwater by means of the waste furnace gases. The boiler room should be designed with a special view to the expeditious handling of coal and ashes with a minimum of labor. To accomplish this, it is well to deliver the coal from a railroad car and unload directly into bunkers, from which it can readily be supplied to the several boilers. These bunkers should have storage capacity for at least 15 days, unless there is another large supply easily accessible. A subway may be built beneath the ash-pits, and these may be fitted with doors to open downwards, through which the ashes can be swept into a small car running on a track beneath. This is a refinement of practice perhaps justifiable only in the case of very large plants.

Provision must be made for a plentiful supply of water. It is not always well to trust entirely to city mains, although this source is usually reliable. When the station is not located near running water, it may be found advisable to sink a well, from which water may be pumped into a tank and the water from the mains used only in cases of emergency.

**9. Steam Piping.**—The steam piping for the station should receive the most careful thought, as it is of the greatest importance, and on its correct design will depend the prime requisite of successful operation, which is, that under no circumstances should there be failure of the current supply to the lines. Some of the engines in many power stations must be kept turning all the time. The simplest means of connection is to supply steam to each engine from an independent boiler, but the objection to this is that, in the event of trouble with any boiler necessitating repairs, its engine would also be put out of service. To overcome this difficulty, the boilers might all be connected together by a steam main, as at $m$, Fig. 1; this is provided with stop valves $v$, $v$, which, with the valves $v_1$ at the engines and those at the boilers $v_2$, afford a means of disconnecting any engine or boiler without affecting the rest of the plant. This system is the cheapest reliable one, but is not the safest, because there is no duplication of pipes, and if one were to burst or otherwise get out of order, the engine or boiler connected to it would be put out of service.

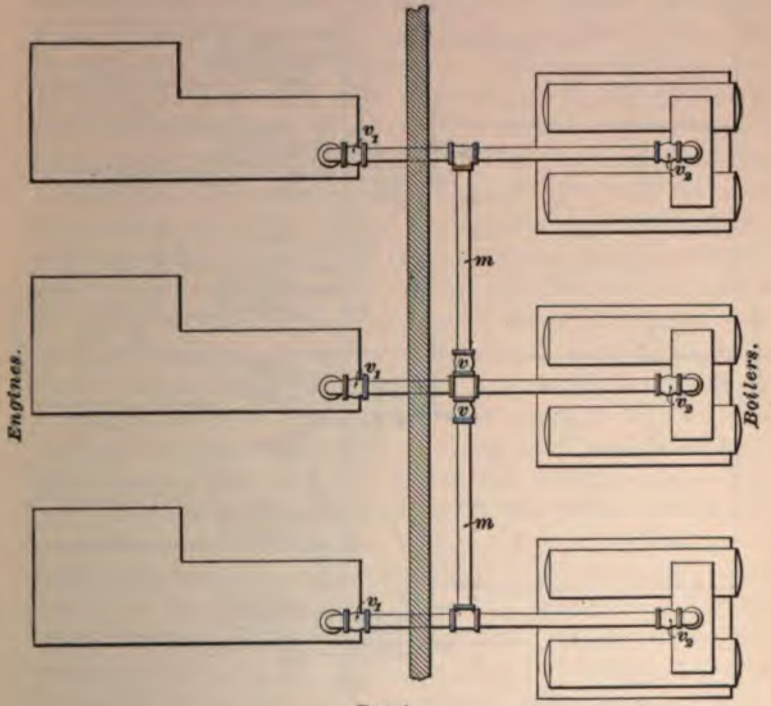

FIG. 1.

**10.** There are two principal methods of installing a duplicate system, and they differ at first sight only in point of size of pipes. A diagram of the arrangement is shown in Fig. 2. Two mains $m$, $m_1$ run the whole length of the boiler room, being connected on one side with leaders to the boilers $a$, $b$, $c$, and on the other with leaders passing through the fire-wall $w$ to the engines. These connecting pipes, it will be seen, are all in pairs, and start from the two mains; each one is provided with a stop valve $v$ at the end, and every pair terminates in a cast-iron **Y**, both at the drum of the boiler and at the engine. This system, therefore, provides a double path for the steam between any engine and any boiler, and renders almost wholly improbable a suspension

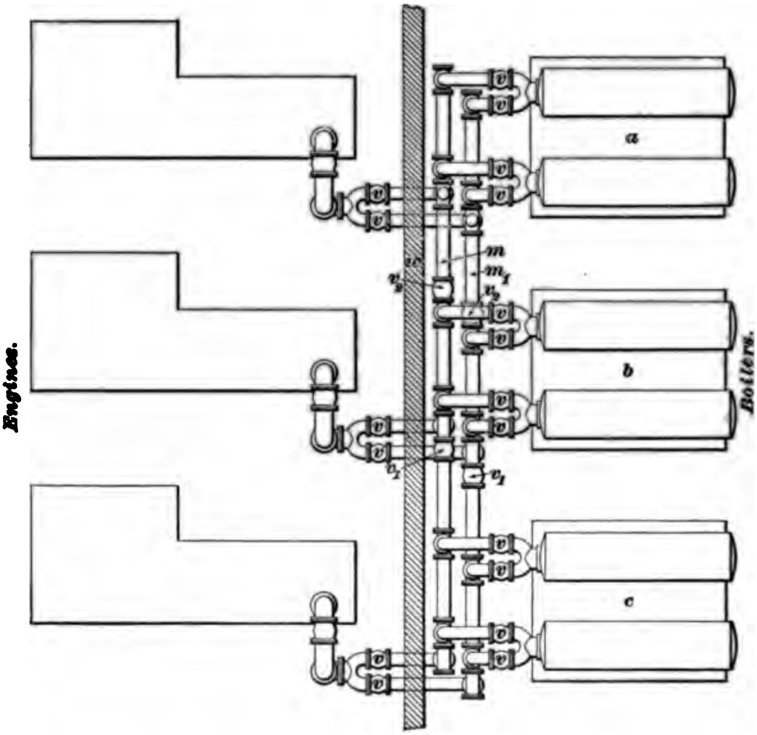

FIG. 2.

of operation due to accident to the steam-power generating plant. The difference alluded to between the two methods of duplicating is that in one system, pipes are provided of such size that one set alone will carry the steam for the engines and the duplicate piping is held as a reserve, while in the other, the pipes are of smaller size and are in use all the time, their combined area of cross-section being necessary for delivering the steam at the determined pressure. The first system is used quite frequently, but has, nevertheless, many disadvantages. It is impossible to keep the valves connecting with the reserve piping closed so tightly that no steam will leak past, and there is always a pressure indicated on the gauge. The exposure of all this surface to condensation, even though protected by nonconducting covering, entails a continual waste of energy, and the drips always have to be left open to prevent the pipes filling up with water. Then, the first cost of such a system is considerably higher than if the smaller pipes were used, and repairs are more expensive. It may also happen that an engineer will habitually use one set of pipes alone for a long period, and when an accident compels him to close this set, he finds that the valves of the auxiliary piping have become seated through rust or deposits from the water and are immovable, and a shut-down is the result. With the second system, the exposed surface of pipes is less, both sides are in service continually, and if an accident should occur to one branch, the remaining branch will furnish steam until a repair is accomplished. There would be, through the one pipe, a greater drop in pressure, but this would easily be remedied by closing the valves $v_1$, $v_1$ or $v_2$, $v_2$ communicating with the rest of the system and running one boiler at a higher pressure for a time. Other methods of piping are sometimes resorted to, but these two, as illustrated in Figs. 1 and 2, will generally be found to satisfy the conditions of simple connections on the one hand or the more expensive but more reliable construction on the other. Generally speaking, it may be said that the use of duplicate steam piping is not as popular as it once was.

Some of the most modern power plants do not use duplicate piping, but take great care to see that everything connected with the single piping is of the best possible quality and has a large factor of safety. If proper care is taken in selecting the material and installing the piping system, there should be little need of putting it up in duplicate.

**11. General Arrangement.**—The general arrangement of a steam plant depends very largely on the style of machinery used. In any event, the boiler room and engine room should be separated from each other by a firewall with fireproof communicating doors. The complete separation of these departments will prevent accumulation of dust on the dynamos and engines due to the handling of coal and ashes. In some cases, where ground space is limited, the engines are placed on one floor and the dynamos on the floor above, the power being transmitted by means of belts. One method uses individual driving from each engine to one or two dynamos located directly above, but a better one is to make use of countershafts on the engine or dynamo floor, or both. These countershafts are divided into sections and fitted with friction pulleys in such a way as to permit of any desired combination of engines and dynamos, an arrangement best calculated to ensure uninterrupted service. A simple example of such an installation is shown in Fig. 3, the lower view being an elevation. The engines are on the lower floor and the countershaft *c* on the upper floor, directly

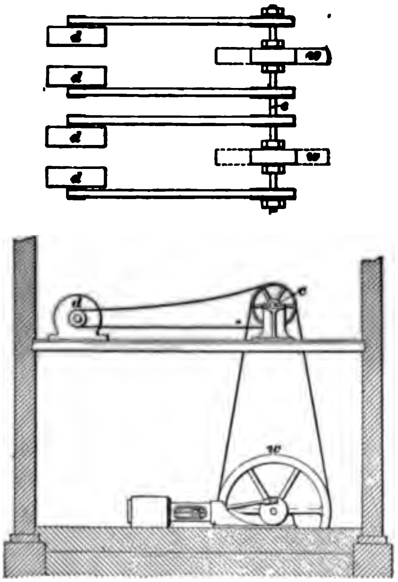

FIG. 3.

above the flywheels and connected by belting to the dynamos *d*. Two engines are indicated, their flywheels *w*, *w* being dotted in the plan.

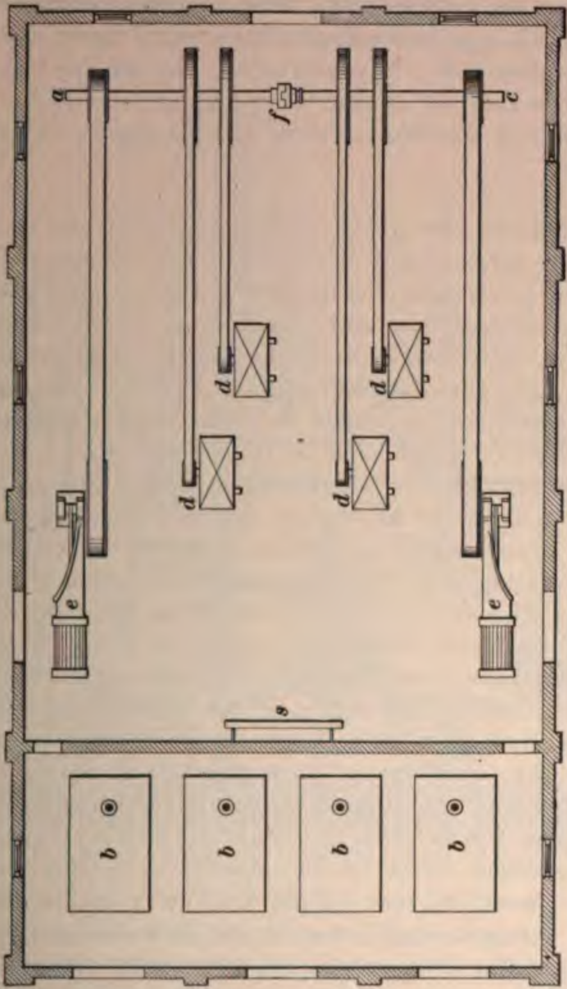

FIG. 4.

**12.** Another plan showing the general arrangement of machinery and boilers for a small station is given in Fig. 4. The engines *e*, *e* are placed near the walls, allowing the whole center of the room for the dynamos *d*. At one end is the countershaft *a c*, which may be divided and fitted with a coupling at *f* for disconnecting one-half of the generating plant when the load is light. The switchboard *s* should be near the dynamos, but not so close as to be liable to injury from a broken belt. Beyond the fire-wall are the boilers *b*, arranged so that the distance from them to the engine shall be as small as possible, to avoid condensation of steam in the pipes.

**13.** The two foregoing plans using belts and countershafts were largely used at one time, but the countershaft in electric-power plants is rapidly going out of existence. The countershaft not only involves a certain waste of power, but it also necessitates the use of a large amount of belting. Now that dynamos are built to run at lower speeds than formerly and are made in larger sizes, the need of a countershaft does not exist to the extent it once did. In medium-sized plants it is now customary either to belt each dynamo directly to its engine or, what is still better, to have the armature of the dynamo mounted directly on the shaft of the engine. This last method of direct driving is becoming almost universal in all large, modern plants. The dynamos used for direct connection must, of course, run slower than those driven by belt, because their speed must suit that of the engine. This means that a direct-connected dynamo must be larger, heavier, and more expensive for the same output than the belt-driven machine. The first cost of the direct-connected machine is, therefore, greater than the belt-driven one. This extra expense is to a certain extent offset by the absence of belting and the decreased wear and tear on the machinery due to the low speed of operation. A great saving in floor space is also gained by using direct-connected generating sets, and this saving of space is an important item in large cities, where ground is very expensive. For small plants, where the first cost must be kept down and where economy of space is not necessary, belted units are still installed in many cases.

**14.** Fig. 5 shows the arrangement of a typical modern central station designed for a large output. The generators *G* are of the multipolar type and are driven directly by the large vertical engines. An electric traveling crane *E* runs the whole length of the dynamo room, so that parts of the engines or dynamos may be easily handled in case repairs are necessary. The condenser *F* is situated in the basement, and in this case both the air pump and circulating pump are driven by electric motors. The boiler room is situated on the left and is separated from the engine room by a fireproof wall. The boilers *B* are of the water-tube

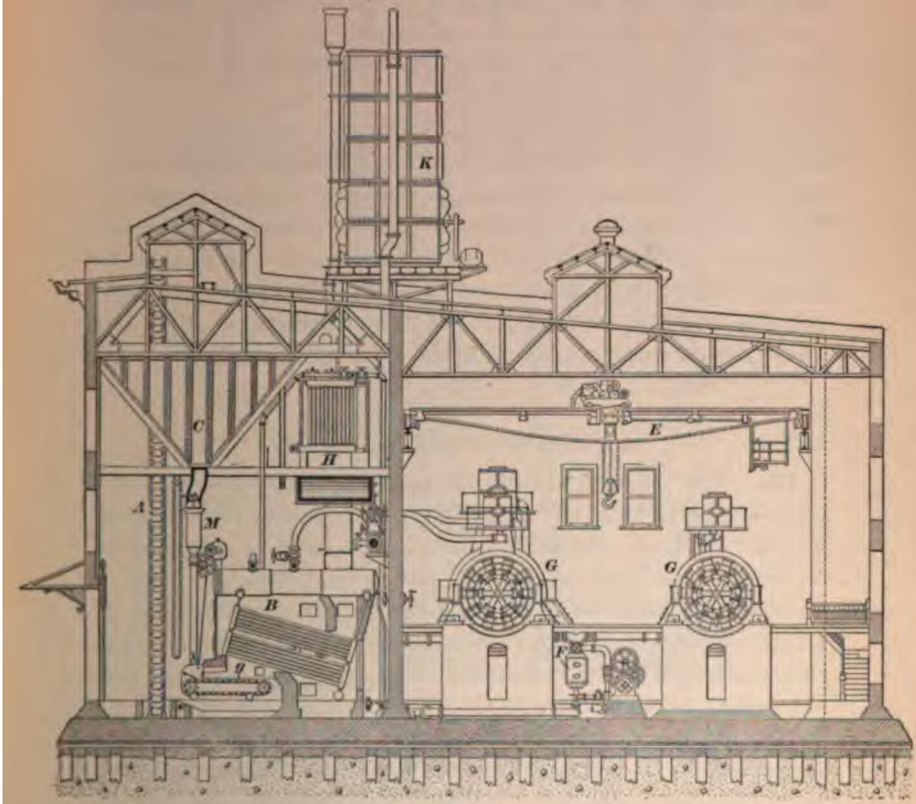

FIG. 5.

type. The hot furnace gases pass through the economizer *H* on their way to the stack, and thus heat up the feedwater before it enters the boilers. Coal is delivered to the hopper *C* by means of the conveyer *A*, and from *C* it is fed to the boilers by means of the chute *M* and the automatic stoker *g*. All the power required for the stokers, coal-handling machinery, etc. is supplied by electric motors. The hot water from the condenser is conveyed to a tower *K*, where it is allowed to fall and come in contact with a current of air set up by fans. The water is cooled by this means, and may be used over again for condensing purposes. The general tendency is towards a centralization of electric light and power plants, while the former practice was to use a number of smaller plants, each located near the district to be supplied. The consequence is that city plants are continually increasing in size, and the plant shown in Fig. 5 is a very fair example of one of these more recent installations.

## WATER-POWER PLANTS.

**15.** The general arrangement of a water-power plant must be made to fit the particular water-power that is used to run the plant. In most cases the station is situated at or near the stream supplying the power, and the type of waterwheel used must be adapted to the head or fall of water obtainable. For electric-power-transmission work, two kinds of waterwheels are in common use, *turbines* and *tangential* or *impulse* wheels. The former are used in by far the greater number of cases, but the latter are especially adapted for use in connection with the high heads met with in mountainous districts. Where waterwheels are used in connection with electric-power-transmission plants, they are frequently coupled directly to the dynamo. The wheel itself in such cases may be of the vertical or horizontal type, but the latter is by far the more common, because it permits the use of ordinary types of dynamo. The most notable example of vertical turbines direct-connected to dynamos is the Niagara plant, part of which is shown in section in Fig. 6. The water from the canal *C* flows into the head-race *H* and thence to the turbines *T* through the penstocks *P*. The wheels are placed at the bottom of the wheel pit and the revolving fields of the generators *G* are carried by the vertical shaft. The water, after leaving the wheels, drops into the tail race *R* and passes off through the tunnel *V* to a point below the falls.

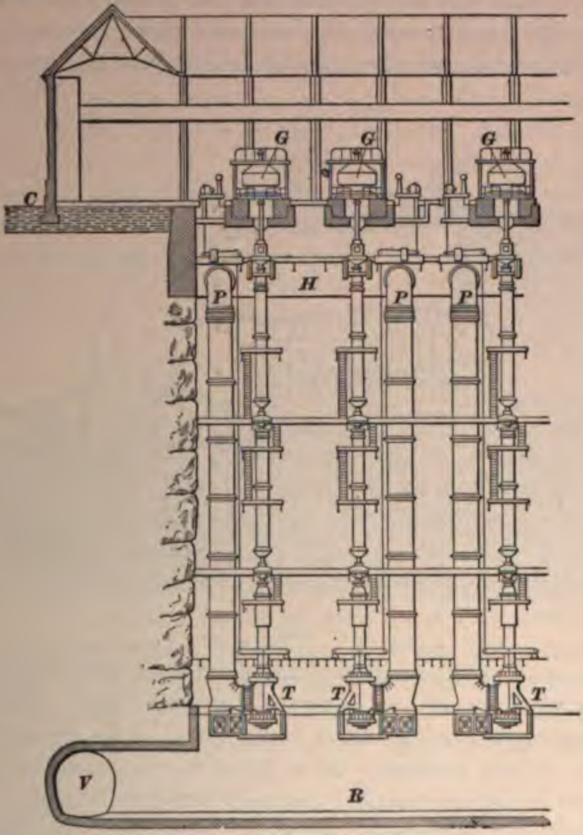

FIG. 6.

**16. Horizontal Turbines.**—Fig. 7 shows a typical arrangement of a horizontal turbine, or rather a pair of turbines. In many cases these turbines are direct-connected to the dynamos, an arrangement that is becoming very common in water-power-transmission plants, where the conditions are suited to this method of operation. It is very compact, and there is no belting or gearing of any kind. Sometimes the turbine and dynamo are both mounted on the same base, while in other plants the turbines are arranged in one room, and the machines are driven by the shafts which extend through into a separate dynamo room. When the dynamos have to run at a high speed, it is necessary, of course, to use belting. In a great many plants the dynamos are driven by vertical turbines through belting or gearing, but the horizontal type is gradually replacing the vertical type for this kind of work.

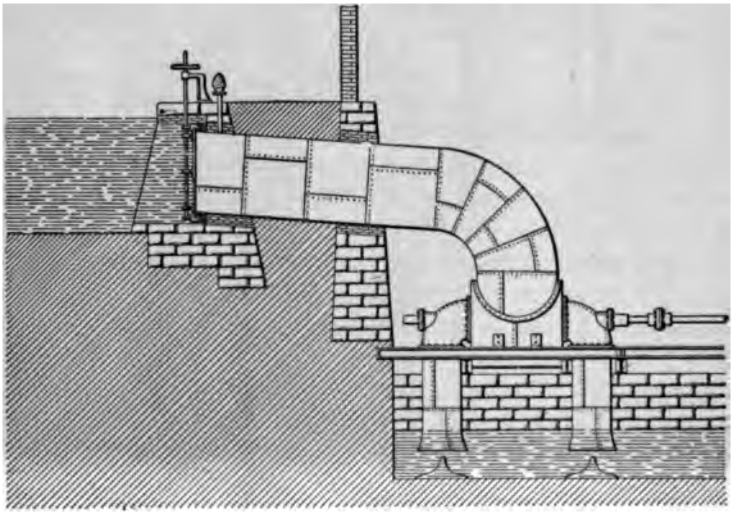

FIG. 7.

## GAS-ENGINE PLANTS.

**17.** Gas engines and oil engines have in the past been used to but a very limited extent in America in connection with electric-power-transmission plants. One of the objections to such engines was that they did not give a steady speed, and, hence, caused fluctuations in voltage. This has been overcome in the later types of engine, and the gas engine will no doubt come largely into use in connection with electrical work. Power can be obtained from coal cheaper by converting the coal into gas and utilizing this gas in a gas engine than by burning the coal under a boiler and using a steam engine. In a gas-engine plant, the boilers would be replaced by gas producers and the steam engines by gas engines. In some few cases natural gas is available, but generally a gas-producing plant would have to be provided. The general arrangement of such a station would be practically the same as that already described for a steam plant.

## LINE CONDUCTORS.

**18.** Before going on with a consideration of the principles involved in electric-power transmission, it will be well to take up briefly the properties of the metals used as conductors. The line wire is, in the vast majority of cases, of copper. Aluminum is now coming into use for this purpose, and in the future it may replace copper for some lines of work. Iron or steel is seldom used for a line conductor, because its resistance is too high. There is one particular case, however, in which it is largely used as a return conductor, and that is in connection with electric railways, where the current is led back to the power house through the rails.

### COPPER CONDUCTORS.

**19. Bare and Insulated Wires.**—Line conductors are usually in the form of copper wire of round cross-section whenever the conductor is of moderate size. For conductors of large cross-section, stranded cables are used, made up of a number of strands of small wire twisted together. This construction makes the conductor flexible and easy to handle. When these wires or cables are strung in the air, they are usually insulated by a covering that consists of two or three braids of cotton, soaked in a weather-proof compound composed largely of pitch or asphalt. If a better insulation is required, the wire is first covered with a layer of rubber and the braid applied over it. For underground work, the conductor is first insulated with rubber or paper soaked in compound and the whole covered with a lead sheath to keep out moisture. Fig. 8 shows a stranded cable for underground work provided with an insulating layer of paper and a lead sheath. Fig. 9 shows an ordinary triple-braid weather-proof overhead line wire, and Fig. 10 a weather-proof overhead cable. When the pressure used on the line is very high, say 10,000 volts or over, bare wires are often used, because the ordinary weather-proof insulation is of little or no protection

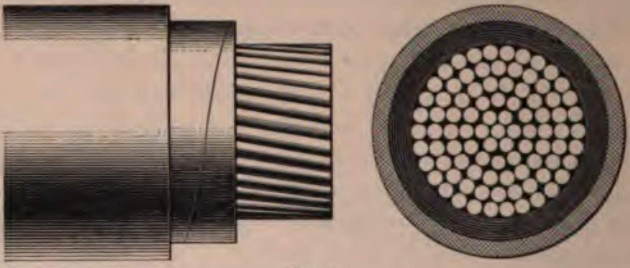

FIG. 8.

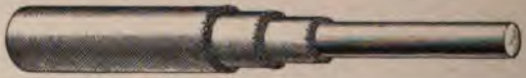

FIG. 9.

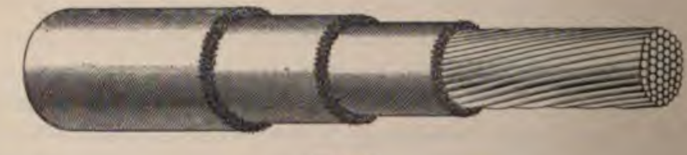

FIG. 10.

against such pressures and only gives a false appearance of security. The practice for such lines is, therefore, to use bare wire and to insulate this wire thoroughly by means of specially designed insulators.

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### WIRE GAUGES.

**20.** Various standards or **wire gauges** have been adopted by different manufacturers, but the safest and best way is always to express the diameter of a wire in *mils*, or thousandths of an inch, and its area of cross-section in *circular mils*. The American, or Brown & Sharpe, gauge is used almost exclusively in America in connection with electrical work, but it is always well to give the diameter of the wire as well as its gauge number, so as to avoid any possibility of mistake.

**21. Circular Measure.**—The diameter of a wire is usually expressed either as a decimal part of an inch or in terms of a unit called the **mil.** A mil is equal to one-thousandth of an inch, i. e., 1 mil = .001 inch. For example, if a wire were two-hundredths of an inch in diameter (.020″), it would have a diameter of 20 mils.

**22.** A **circular mil** is a unit of area used in expressing the area of cross-section of wires. It will be seen later that a simple relation exists between the diameter of a wire and its area of cross-section expressed in circular mils, so that if either one of these quantities is known the other can be readily obtained. If the diameter of a circle is $d$ inches, its area in square inches is $d^2 \times .7854$. If $d$ is expressed in mils, the area, calculated in the same manner, will be given in square mils.

**23.** The square inch is not a convenient unit to use for expressing the area of cross-section of wires because, in the first place, it is too large, and, in the second place, the quantity .7854 makes the calculations awkward to perform rapidly. In order to get around these difficulties, the circular mil is used for expressing the area of cross-section. The circular mil is the area enclosed by a circle of which the diameter is one mil, or one one-thousandth of an inch. Its area is therefore $\left(\frac{1}{1000}\right)^2 \times .7854$, or .0000007854 square inch. Suppose now that we have a wire the diameter of which is $d$ mils. Its area in square inches will be $\left(\frac{d}{1,000}\right)^2 \times .7854$. But we have seen above that the area of 1 circular mil is .0000007854 square inch, hence the number of circular mils that there must be in a wire of diameter $d$ mils is $\frac{\left(\frac{d}{1,000}\right)^2 \times .7854}{\left(\frac{1}{1000}\right)^2 \times .7854} = d^2$; or, *the number of circular mils cross-section of a wire is equal to the square of its diameter expressed in mils.* If, then, we know the diameter of any wire, we can at once obtain its area in circular mils by expressing the diameter in mils and squaring it.

EXAMPLE 1.—A round wire has a diameter of .036 inch; what is its diameter in mils and its area in circular mils?

SOLUTION.—Since 1 mil = .001 inch, the diameter will be 36 mils. Circular mils = $d^2 = 36^2 = 1,296$. Ans.

EXAMPLE 2.—What would be the area of the above wire in square mils?

SOLUTION.—Area in square mils = $d^2 \times .7854$, where $d$ is the diameter in mils. Hence, square mils = $d^2 \times .7854 = 1,296 \times .7854 = 1,018$, nearly. Ans.

EXAMPLE 3.—Find the area in circular mils of a round copper rod ¼ inch in diameter.

SOLUTION.— ¼ inch = .250 inch = 250 mils; hence, area in circular mils = $250^2 = 62,500$. Ans.

EXAMPLE 4.—Find the area in square mils of a ½-inch square, copper bar.

SOLUTION.— ½ inch = .500 inch = 500 mils. Area in square mils = $500 \times 500 = 250,000$. Ans.

EXAMPLE 5.—A round rod has an area of 125,000 circular mils: what is its diameter in mils?

SOLUTION.—We have area in circular mils = $d^2$, or $d = \sqrt{\text{area in circular mils}} = \sqrt{125,000} = 354$ mils, nearly, or about .354 in. Ans

# TABLE I.

## DIFFERENT STANDARDS FOR WIRE GAUGE.

*Dimensions of Wires in Decimal Parts of an Inch.*

| Number of Wire Gauge. | American, or Brown & Sharpe. | Birmingham, or Stubs. | Washburn & Moen M'f'g Co., Worcester, Mass. | Trenton Iron Co., Trenton, N. J. | G. W. Prentiss, Holyoke, Mass. | Old English, From Brass Mfrs'. List. | British Standard. | Number of Wire Gauge. |
|---|---|---|---|---|---|---|---|---|
| 000000 | | | .4600 | | | | | 000000 |
| 00000 | | | .4300 | .4500 | | | | 00000 |
| 0000 | .460000 | .454 | .3930 | .4000 | | | | 0000 |
| 000 | .409640 | .425 | .3620 | .3600 | .3586 | | | 000 |
| 00 | .364800 | .380 | .3310 | .3300 | .3282 | | | 00 |
| 0 | .324860 | .340 | .3070 | .3050 | .2994 | | | 0 |
| 1 | .289300 | .300 | 2830 | .2850 | .2777 | | | 1 |
| 2 | .257630 | .284 | .2630 | .2650 | .2591 | | | 2 |
| 3 | .229420 | .259 | .2440 | .2450 | .2401 | | | 3 |
| 4 | .204310 | .238 | .2250 | .2250 | .2230 | | .2320 | 4 |
| 5 | .181940 | .220 | .2070 | .2050 | .2047 | | .2120 | 5 |
| 6 | .162020 | .203 | .1920 | .1900 | .1885 | | .1920 | 6 |
| 7 | .144280 | .180 | .1770 | .1750 | .1758 | | .1760 | 7 |
| 8 | .128490 | .165 | .1620 | .1600 | .1605 | | .1600 | 8 |
| 9 | .114430 | .148 | .1480 | .1450 | .1471 | | .1440 | 9 |
| 10 | .101890 | .134 | .1350 | .1300 | .1351 | | .1280 | 10 |
| 11 | .090742 | .120 | .1200 | .1175 | .1205 | | .1160 | 11 |
| 12 | .080808 | .109 | .1050 | .1050 | .1065 | | .1040 | 12 |
| 13 | .071961 | .095 | .0920 | .0925 | .0928 | | .0920 | 13 |
| 14 | .064084 | .083 | .0800 | .0800 | .0816 | .08300 | .0800 | 14 |
| 15 | .057068 | .072 | .0720 | .0700 | .0726 | .07200 | .0720 | 15 |
| 16 | .050820 | .065 | .0630 | .0610 | .0627 | .06500 | .0640 | 16 |
| 17 | .045257 | .058 | .0540 | .0525 | .0546 | .05800 | .0560 | 17 |
| 18 | .040303 | .049 | .0470 | .0450 | .0478 | .04900 | .0480 | 18 |
| 19 | .035890 | .042 | .0410 | .0400 | .0411 | .04000 | .0400 | 19 |
| 20 | .031961 | .035 | .0350 | .0350 | .0351 | .03500 | .0360 | 20 |
| 21 | .028462 | .032 | .0320 | .0310 | .0321 | .03150 | .0320 | 21 |
| 22 | .025347 | .028 | .0280 | .0280 | .0290 | .02950 | .0280 | 22 |
| 23 | 022571 | .025 | .0250 | .0250 | .0261 | .02700 | .0240 | 23 |
| 24 | 020100 | .022 | .0230 | .0225 | .0231 | .02500 | .0220 | 24 |
| 25 | .017900 | .020 | .0200 | .0200 | .0212 | .02300 | .0200 | 25 |
| 26 | .015940 | .018 | .0180 | .0180 | .0194 | .02050 | .0180 | 26 |
| 27 | 014195 | .016 | .0170 | .0170 | .0182 | .01875 | .0164 | 27 |
| 28 | .012641 | .014 | .0160 | .0160 | .0170 | .01650 | .0148 | 28 |
| 29 | 011257 | .013 | .0150 | .0150 | .0163 | .01550 | .0136 | 29 |
| 30 | .010025 | .012 | .0140 | .0140 | .0156 | .01375 | .0124 | 30 |
| 31 | 008928 | .010 | .0135 | .0130 | .0146 | .01225 | .0116 | 31 |
| 32 | .007950 | .009 | .0130 | .0120 | .0136 | .01125 | .0108 | 32 |
| 33 | .007080 | .008 | .0110 | .0110 | .0130 | .01025 | .0100 | 33 |
| 34 | 006304 | .007 | .0100 | .0100 | .0118 | .00950 | .0092 | 34 |
| 35 | .005614 | .005 | .0095 | .0095 | .0109 | .00900 | .0084 | 35 |
| 36 | .005000 | .004 | .0090 | .0090 | .0100 | .00750 | .0076 | 36 |
| 37 | 004453 | | .0085 | .0085 | .0095 | .00650 | .0068 | 37 |
| 38 | 003965 | | .0080 | .0080 | .0090 | .00575 | .0060 | 38 |
| 39 | .003531 | | .0075 | .0075 | .0083 | .00500 | .0052 | 39 |
| 40 | .003144 | | .0070 | .0070 | .0078 | .00450 | .0048 | 40 |
| 41 | | | | | | | .0044 | 41 |
| 42 | | | | | | | .0040 | 42 |

# TABLE II.

## DIMENSIONS, WEIGHT, ETC. OF BARE COPPER WIRE.

*American, or B. & S., Gauge.*

| Gauge No.—B. & S. | Diameter in Mils, or $\frac{1}{1000}$ Inch. | Area in Circular Mils. C. M. = $d^2$. | Area in Square Inches. Area = $\frac{d^2}{1,000,000} \times .7854$. | WEIGHTS—SPECIFIC GRAVITY, 8.89. | | | | RESISTANCE AT 68° F., IN INTERNATIONAL OHMS, BASED ON MATTHIESSEN'S STANDARD. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Ohms per 1,000 Feet. | | Ohms per Mile. | | |
| | $d$ | $d^2$ | | Pounds per 1,000 Feet. | Pounds per Mile. | Feet per Pound. | Ohms per Pound, Annealed. | Pure Annealed. | Hard Drawn. | Pure Annealed. | Hard Drawn. | Feet per Ohm, Annealed. |
| 0000 | 460.000 | 211,600.00 | .1661900000 | 640.50000 | 3,381.400 | 1.561 | .00007639 | .04893 | .050036 | .25835 | .26419 | 20,440.000 |
| 000 | 409.640 | 167,805.00 | .1317900000 | 508.00000 | 2,682.200 | 1.969 | .00012150 | .06170 | .063094 | .32577 | .33314 | 16,210.000 |
| 00 | 364.800 | 133,079.40 | .1045200000 | 402.80000 | 2,126.800 | 2.482 | .00019310 | .07780 | .079558 | .41079 | .42007 | 12,850.000 |
| 0 | 324.865 | 105,534.50 | .0828870000 | 319.50000 | 1,686.900 | 3.130 | .00030710 | .09811 | .100330 | .51802 | .52973 | 10,190.000 |
| 1 | 289.300 | 83,694.20 | .0657320000 | 253.30000 | 1,337.200 | 3.947 | .00048830 | .12370 | .126490 | .65314 | .66790 | 8,083.000 |
| 2 | 257.630 | 66,373.00 | .0521280000 | 200.90000 | 1,060.600 | 4.977 | .00077650 | .15600 | .159530 | .82368 | .84239 | 6,410.000 |
| 3 | 229.420 | 52,634.00 | .0413390000 | 159.30000 | 841.090 | 6.276 | .00123500 | .19670 | .201140 | 1.03860 | 1.06210 | 5,084.000 |
| 4 | 204.310 | 41,742.00 | .0327840000 | 126.40000 | 667.390 | 7.914 | .00196300 | .24800 | .253610 | 1.30940 | 1.33920 | 4,031.000 |
| 5 | 181.940 | 33,102.00 | .0259990000 | 100.20000 | 529.060 | 9.980 | .00312200 | .31280 | .319870 | 1.65160 | 1.68890 | 3,197.000 |
| 6 | 162.020 | 26,250.50 | .0206180000 | 79.46000 | 419.550 | 12.580 | .00496300 | .39440 | .403320 | 2.08250 | 2.12950 | 2,535.000 |
| 7 | 144.280 | 20,816.00 | .0163510000 | 63.02000 | 332.750 | 15.870 | .00789200 | .49730 | .508540 | 2.62580 | 2.68500 | 2,011.000 |
| 8 | 128.490 | 16,509.00 | .0129670000 | 49.98000 | 263.890 | 20.010 | .01255000 | .62710 | .641270 | 3.31110 | 3.38590 | 1,595.000 |
| 9 | 114.430 | 13,094.00 | .0102830000 | 39.63000 | 209.240 | 25.230 | .01995000 | .79080 | .808760 | 4.17530 | 4.27690 | 1,265.000 |
| 10 | 101.890 | 10,381.00 | .0081548000 | 31.43000 | 165.950 | 31.820 | .03173000 | .99720 | 1.019900 | 5.26570 | 5.38480 | 1,003.000 |
| 11 | 90.742 | 8,234.00 | .0064656000 | 24.93000 | 131.630 | 40.120 | .05045000 | 1.25700 | 1.285400 | 6.63690 | 6.78690 | 795.300 |
| 12 | 80.808 | 6,529.90 | .0051287000 | 19.77000 | 104.390 | 50.590 | .08022000 | 1.58600 | 1.621800 | 8.37410 | 8.56330 | 630.700 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 71.961 | 5,178.40 | .0040672000 | 15.68000 | 82.791 | 63.790 | .12760000 | 1.99900 | 2.044300 | 10.55500 | 10.79400 | 500.100 |
| 14 | 64.084 | 4,106.80 | .0032254000 | 12.43000 | 76.191 | 80.440 | .20280000 | 2.52100 | 2.577900 | 13.31100 | 13.61200 | 396.600 |
| 15 | 57.068 | 3,256.70 | .0025579000 | 9.85800 | 52.050 | 101.400 | .32250000 | 3.17900 | 3.250800 | 16.78500 | 17.16500 | 314.500 |
| 16 | 50.820 | 2,582.90 | .0020285000 | 7.81800 | 41.277 | 127.900 | .51280000 | 4.00900 | 4.099600 | 21.16800 | 21.64600 | 249.400 |
| 17 | 45.257 | 2,048.20 | .0016087000 | 6.20000 | 32.736 | 161.300 | .81530000 | 5.05500 | 5.169200 | 26.69100 | 27.29400 | 197.800 |
| 18 | 40.303 | 1,624.30 | .0012757000 | 4.91700 | 25.960 | 203.400 | 1.29600000 | 6.37400 | 6.518300 | 33.65500 | 34.41600 | 156.900 |
| 19 | 35.890 | 1,288.10 | .0010117000 | 3.89900 | 20.595 | 256.500 | 2.06100000 | 8.03800 | 8.219600 | 42.44100 | 43.40000 | 124.400 |
| 20 | 31.961 | 1,021.50 | .0008023100 | 3.09200 | 16.324 | 323.400 | 3.27800000 | 10.14000 | 10.372000 | 53.53900 | 54.74900 | 98.660 |
| 21 | 28.462 | 810.10 | .0006362600 | 2.45200 | 12.946 | 407.800 | 5.21200000 | 12.78000 | | 67.47900 | | 78.240 |
| 22 | 25.347 | 642.40 | .0005045700 | 1.94500 | 10.268 | 514.200 | 8.28700000 | 16.12000 | | 85.11400 | | 62.050 |
| 23 | 22.571 | 509.45 | .0004001500 | 1.54200 | 8.142 | 648.400 | 13.18000000 | 20.32000 | | 107.29000 | | 49.210 |
| 24 | 20.100 | 404.01 | .0003173300 | 1.22300 | 6.457 | 817.600 | 20.95000000 | 25.63000 | | 135.53000 | | 39.020 |
| 25 | 17.900 | 320.40 | .0002516600 | .96990 | 5.121 | 1,031.000 | 33.32000000 | 32.31000 | | 170.59000 | | 30.950 |
| 26 | 15.940 | 254.10 | .0001995800 | .76920 | 4.061 | 1,300.000 | 52.97000000 | 40.75000 | | 215.16000 | | 24.540 |
| 27 | 14.195 | 201.50 | .0001582700 | .61000 | 3.221 | 1,639.000 | 84.23000000 | 51.38000 | | 271.29000 | | 19.460 |
| 28 | 12.641 | 159.79 | .0001255100 | .48370 | 2.554 | 2,067.000 | 133.90000000 | 64.79000 | | 242.09000 | | 15.430 |
| 29 | 11.257 | 126.72 | .0000995360 | .38360 | 2.025 | 2,607.000 | 213.00000000 | 81.70000 | | 431.37000 | | 12.240 |
| 30 | 10.025 | 100.50 | .0000789360 | .30420 | 1.606 | 3,287.000 | 338.60000000 | 103.00000 | | 543.84000 | | 9.707 |
| 31 | 8.928 | 79.70 | .0000625990 | .24130 | 1.274 | 4,145.000 | 538.40000000 | 129.90000 | | 685.87000 | | 7.698 |
| 32 | 7.950 | 63.21 | .0000496430 | .19130 | 1.010 | 5,227.000 | 856.20000000 | 163.80000 | | 864.87000 | | 6.105 |
| 33 | 7.080 | 50.13 | .0000393680 | .15170 | .801 | 6,591.000 | 1,361.00000000 | 206.60000 | | 1,090.80000 | | 4.841 |
| 34 | 6.305 | 39.75 | .0000312210 | .12030 | .635 | 8,311.000 | 2,165.00000000 | 260.50000 | | 1,375.50000 | | 3.839 |
| 35 | 5.615 | 31.52 | .0000247590 | .09543 | .504 | 10,480.000 | 3,441.00000000 | 328.40000 | | 1,734.00000 | | 3.045 |
| 36 | 5.000 | 25.00 | .0000196350 | .07568 | .400 | 13,210.000 | 5,473.00000000 | 414.20000 | | 2,187.00000 | | 2.414 |
| 37 | 4.453 | 19.83 | .0000155740 | .06001 | .317 | 16,660.000 | 8,702.00000000 | 522.20000 | | 2,757.30000 | | 1.915 |
| 38 | 3.965 | 15.72 | .0000123450 | .04759 | .251 | 21,010.000 | 13,870.00000000 | 658.50000 | | 3,476.80000 | | 1.519 |
| 39 | 3.531 | 12.47 | .0000097923 | .03774 | .199 | 26,500.000 | 22,000.00000000 | 830.40000 | | 4,384.50000 | | 1.204 |
| 40 | 3.145 | 9.89 | .0000077634 | .02993 | .158 | 33,410.000 | 34,980.00000000 | 1,047.00000 | | 5,528.20000 | | .955 |

**24. The Brown & Sharpe Gauge.**—This gauge is usually termed the **B. & S. gauge,** and is generally used in the United States for designating the sizes of copper wire. The sizes of wire as given by this gauge range from No. 0000, which has a diameter of .460 inch, to No. 40, which has a diameter of .0031 inch; the higher the gauge number the smaller the wire. The rule by which the sizes of wire increase as the gauge number diminishes is a very simple one. If we take any given gauge number as a basis of comparison, a wire three numbers higher will have very nearly half the cross-section, and one three numbers lower will have twice the cross-section. For example, a No. 4 wire has twice the cross-section of a No. 7, and a No. 10 has one-half the cross-section of a No. 7.

**25.** Another point that is useful to bear in mind in reference to the B. & S. gauge is that a No. 10 wire has a diameter of very nearly $\frac{1}{10}$ inch and that its resistance per 1,000 feet is almost exactly 1 ohm. By remembering the foregoing properties of this gauge and the figures relating to the No. 10 wire, rough calculations may be made as to the diameter and resistance of other sizes. It is better, however, to consult a good wire table than attempt to burden the mind with a lot of rules. A number of other gauges are in use, and as the student may sometimes find wires given in terms of these, Table I is given, showing the diameters of wires according to the different gauges.

**26.** Table II gives the properties of copper wire according to the B. &. S. gauge. Sizes smaller than No. 14 are seldom used for electric transmission, but the complete table is given for reference, as the small sizes are largely used in connection with the windings of various types of electrical apparatus. The resistances as given in this table are based on the standard used by Matthiessen in his experiments; if the purity of the copper is not up to this standard, its resistance may run somewhat higher than the values given in the table, but the difference will not be very great, because copper wire, as now manufactured, is remarkably pure. All the weights given are, of course, for bare copper wire.

**27.** Table III gives the approximate weights of weather-proof line wire, such as is used for ordinary outside lines.

### TABLE III.

### APPROXIMATE WEIGHTS OF WEATHER-PROOF WIRE.

(*American Electrical Works.*)

TRIPLE-BRAIDED INSULATION.

| Size. | Feet per Pound. | Pounds per 1,000 Feet. | Pounds per Mile. | Carrying Capacity, Amperes, National Board Fire Underwriters. |
|---|---|---|---|---|
| 4–0 | 1.34 | 742 | 3,920 | 312 |
| 3–0 | 1.64 | 609 | 3,215 | 262 |
| 2–0 | 2.05 | 487 | 2,570 | 220 |
| 0 | 2.59 | 386 | 2,040 | 185 |
| 1 | 3.25 | 308 | 1,625 | 156 |
| 2 | 4.10 | 244 | 1,289 | 131 |
| 3 | 5.15 | 194 | 1,025 | 110 |
| 4 | 6.26 | 160 | 845 | 92 |
| 5 | 7.46 | 134 | 710 | 77 |
| 6 | 9.00 | 111 | 585 | 65 |
| 8 | 13.00 | 73 | 385 | 46 |
| 10 | 20.00 | 50 | 265 | 32 |
| 12 | 29.00 | 35 | 182 | 23 |
| 14 | 38.00 | 26 | 137 | 16 |
| 16 | 48.00 | 21 | 113 | 8 |
| 18 | 67.00 | 15 | 81 | 5 |

## TABLE III.—*Continued.*

### Double-Braided Insulation.

| Size. | Feet per Pound. | Pounds per 1,000 Feet. | Pounds per Mile. | Carrying Capacity, Amperes, National Board Fire Underwriters. |
|---|---|---|---|---|
| 4–0 | 1.40 | 711 | 3,754 | 312 |
| 3–0 | 1.75 | 570 | 3,010 | 262 |
| 2–0 | 2.29 | 436 | 2,300 | 220 |
| 0 | 2.81 | 355 | 1,875 | 185 |
| 1 | 3.56 | 281 | 1,482 | 156 |
| 2 | 4.49 | 223 | 1,175 | 131 |
| 3 | 5.45 | 184 | 969 | 110 |
| 4 | 6.82 | 147 | 774 | 92 |
| 5 | 9.10 | 110 | 580 | 77 |
| 6 | 10.35 | 97 | 510 | 65 |
| 8 | 15.52 | 64 | 340 | 46 |
| 10 | 22.00 | 45 | 237 | 32 |
| 12 | 40.00 | 25 | 132 | 23 |
| 14 | 56.00 | 18 | 95 | 16 |
| 16 | 76.00 | 13 | 69 | 8 |
| 18 | 100.00 | 10 | 53 | 5 |

**28.** Table IV gives the approximate dimensions of stranded insulated weather-proof cables for overhead work. The area of cross-section of such cables is always designated as so many circular mils, and not by gauge number. In fact, any conductor larger than No. 0000 is usually designated by its area in circular mils. Cables such as those given in Table IV are extensively used for street-railway feeders or for any other purpose requiring a large conductor.

### ALUMINUM CONDUCTORS.

**29.** Mention has already been made of the fact that aluminum is being used for electrical conductors, because this metal can now be sold at a figure low enough to

## TABLE IV.

### STANDARD WEATHER-PROOF FEED-WIRE.

(*Roebling's.*)

| Circular Mils. | Outside Diameters. Inches. | Weights. Pounds. | | Approximate Length on Reels. Feet. | Carrying Capacity, National Board Fire Underwriters. |
|---|---|---|---|---|---|
| | | 1,000 Feet. | Mile. | | |
| 1,000,000 | $1\frac{1}{2}$ | 3,550 | 18,744 | 800 | 1,000 |
| 900,000 | $1\frac{13}{32}$ | 3,215 | 16,975 | 800 | 920 |
| 800,000 | $1\frac{11}{32}$ | 2,880 | 15,206 | 850 | 840 |
| 750,000 | $1\frac{5}{16}$ | 2,713 | 14,325 | 850 | |
| 700,000 | $1\frac{9}{32}$ | 2,545 | 13,438 | 900 | 760 |
| 650,000 | $1\frac{1}{4}$ | 2,378 | 12,556 | 900 | |
| 600,000 | $1\frac{7}{32}$ | 2,210 | 11,668 | 1,000 | 680 |
| 550,000 | $1\frac{3}{16}$ | 2,043 | 10,787 | 1,200 | |
| 500,000 | $1\frac{1}{8}$ | 1,875 | 9,900 | 1,320 | 590 |
| 450,000 | $1\frac{3}{32}$ | 1,703 | 8,992 | 1,400 | |
| 400,000 | $1\frac{1}{16}$ | 1,530 | 8,078 | 1,450 | 500 |
| 350,000 | 1 | 1,358 | 7,170 | 1,500 | |
| 300,000 | $1\frac{15}{16}$ | 1,185 | 6,257 | 1,600 | 400 |
| 250,000 | $\frac{29}{32}$ | 1,012 | 5,343 | 1,600 | |

compete with copper. Its conductivity is only about 60 per cent. that of copper, so that for a conductor of the same resistance a larger cross-section is required. Aluminum is, however, so much lighter than copper that the larger cross-section can be used and still compete with the latter metal, although the cost per pound of the aluminum may be considerably higher. Line-construction work is somewhat more difficult with aluminum than with copper; joints are more difficult to make and there is greater liability of the spans breaking. A comparison of some of the properties of aluminum and copper is given in Table V.

### TABLE V.

COMPARISON OF PROPERTIES OF COPPER AND ALUMINUM.

| | Aluminum. | Copper. |
|---|---|---|
| Conductivity (for equal sizes)...... | .54 to .63 | 1. |
| Weight (for equal sizes)........... | .33 | 1. |
| Weight (for equal length and resistance)...................... | .48 | 1. |
| Price, Al. 29c.; Cop. 16c. (bare line wire)......................... | 1.81 | 1. |
| Price (equal resistance and length, bare line wire)................. | .868 | 1. |
| Temperature coefficient per degree F........................ | .002138 | .002155 |
| Resistance of mil-foot (20° C.)..... | 18.73 | 10.05 |
| Specific gravity.................. | 2.5 to 2.68 | 8.89to8.93 |
| Breaking strength (equal sizes).... | 1. | 1. |
| Tensile strength (pounds per sq. in., hard drawn)................... | 40,000 | 60,000 |
| Coefficient of expansion per degree F........................ | .0000231 | .0000093 |

## IRON WIRE.

**30.** Iron wire is used largely for telegraph and telephone work, but it is seldom employed in connection with electric transmission because of its high resistance. The approximate value of the resistance per mile of a good quality of iron wire may be determined from the formula

$$R = \frac{360{,}000}{d^2}, \qquad (1.)$$

where $d$ = diameter of wire in mils.

## TABLE VI.

### DIMENSIONS AND RESISTANCE OF IRON WIRE.

| Number B. W. G. | Diameter in Mils = $d$. | Area in Circular Mils = $d^2$. | Weight in Pounds. | | Breaking Strengths in Pounds. | | Resistance per Mile at 68° F. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1,000 Feet. | One Mile. | Iron. | Steel. | E. B. B. | B. B. | Steel. |
| 0 | 340 | 115,600 | 304.0 | 1,607 | 4,821 | 9,079 | 2.93 | 3.42 | 4.05 |
| 1 | 300 | 90,000 | 237.0 | 1,251 | 3,753 | 7,068 | 3.76 | 4.40 | 5.20 |
| 2 | 284 | 80,656 | 212.0 | 1,121 | 3,363 | 6,335 | 4.19 | 4.91 | 5.80 |
| 3 | 259 | 67,081 | 177.0 | 932 | 2,796 | 5,268 | 5.04 | 5.90 | 6.97 |
| 4 | 238 | 56,644 | 149.0 | 787 | 2,361 | 4,449 | 5.97 | 6.99 | 8.26 |
| 5 | 220 | 48,400 | 127.0 | 673 | 2,019 | 3,801 | 4.99 | 8.18 | 9.66 |
| 6 | 203 | 41,209 | 109.0 | 573 | 1,719 | 3,237 | 8.21 | 9.60 | 11.35 |
| 7 | 180 | 32,400 | 85.0 | 450 | 1,350 | 2,545 | 10.44 | 12.21 | 14.43 |
| 8 | 165 | 27,225 | 72.0 | 378 | 1,134 | 2,138 | 12.42 | 14.53 | 17.18 |
| 9 | 148 | 21,904 | 58.0 | 305 | 915 | 1,720 | 15.44 | 18.06 | 21.35 |
| 10 | 134 | 17,956 | 47.0 | 250 | 750 | 1,410 | 18.83 | 22.04 | 26.04 |
| 11 | 120 | 14,400 | 38.0 | 200 | 600 | 1,131 | 23.48 | 27.48 | 32.47 |
| 12 | 109 | 11,881 | 31.0 | 165 | 495 | 933 | 28.46 | 33.30 | 39.36 |
| 13 | 95 | 9,025 | 24.0 | 125 | 375 | 709 | 37.47 | 43.85 | 51.82 |
| 14 | 83 | 6,889 | 18.0 | 96 | 288 | 541 | 29.08 | 57.44 | 67.88 |
| 15 | 72 | 5,184 | 13.7 | 72 | 216 | 407 | 65.23 | 76.33 | 90.21 |
| 16 | 65 | 4,225 | 11.1 | 59 | 177 | 332 | 80.03 | 93.66 | 110.70 |
| 17 | 58 | 3,364 | 8.9 | 47 | 141 | 264 | 100.50 | 120.40 | 139.00 |
| 18 | 49 | 2,401 | 6.3 | 33 | 99 | 189 | 140.80 | 164.80 | 194.80 |

For steel wire, which is often used in place of iron wire, this formula becomes approximately

$$R = \frac{470,000}{d^2}. \qquad (2.)$$

**31.** The various grades of iron wire on the market are termed "Extra Best Best," "Best Best," and "Best." A steel wire is also used, which is cheaper and of higher resistance than iron. It has an advantage, however, of possessing greater tensile strength. It should not be used except on short lines or in special cases where it is desirable to

## TABLE VII.

### GERMAN-SILVER WIRE.

*(Roebling's.)*

| Number B. & S. Gauge. | Resistance per 1,000 Feet. International Ohms. |  | Maximum Current Carrying Capacity in Amperes. 18% wire. |
|---|---|---|---|
|  | 18%. | 30%. |  |
| 6 | 7.20 | 11.21 |  |
| 7 | 9.12 | 14.18 |  |
| 8 | 11.54 | 17.95 |  |
| 9 | 14.55 | 22.63 |  |
| 10 | 18.18 | 28.28 | 8.5 |
| [illegible] | 22.84 | 35.53 | 5.4 |
| [illegible] | 28.81 | 44.82 | 4.6 |
| [illegible] | 36.48 | 56.75 | 3.8 |
| 14 | 46.17 | 71.82 | 3.2 |
| 15 | 58.21 | 90.55 | 2.7 |
| 16 | 72.72 | 113.12 | 2.3 |
| 17 | 93.40 | 145.29 | 1.9 |
| 18 | 118.20 | 183.87 | 1.65 |
| 19 | 145.94 | 227.02 | 1.21 |
| 20 | 184.68 | 287.28 | .99 |
| 21 | 232.92 | 362.32 | .88 |
| 22 | 295.38 | 459.48 | .66 |
| 23 | 370.26 | 575.96 | .55 |
| 24 | 468.18 | 728.28 | .488 |
| 25 | 590.22 | 918.12 | .434 |
| 26 | 748.08 | 1,163.68 | .385 |
| 27 | 937.98 | 1,459.08 | .343 |
| 28 | 1,191.24 | 1,853.04 |  |
| 29 | 1,481.22 | 2,304.12 |  |
| 30 | 1,891.80 | 2,942.80 |  |
| 31 | 2,388.60 | 3,715.60 |  |
| 32 | 2,955.60 | 4,597.60 |  |
| 33 | 3,751.20 | 5,835.20 |  |
| 34 | 4,764.60 | 7,411.60 |  |
| 35 | 6,031.80 | 9,382.80 |  |
| 36 | 7,565.40 | 11,768.40 |  |

have great tensile strength. Table VI gives the weight, resistance, etc. of iron wire according to the Birmingham wire gauge, which is most commonly used in connection with iron wire.

### GERMAN-SILVER WIRE.

**32.** German-silver wire is used principally in resistance boxes or electrical instruments where a high resistance is required. The resistance of this wire varies greatly according to the materials and methods of manufacture used. It is an alloy of copper, nickel, and zinc, and has a resistance anywhere from 18 to 28 times that of copper. Its resistance changes only to a small extent with changes in temperature, a feature of value in connection with rheostats and resistance boxes. Table VII gives some of the properties of German-silver wire containing 18 or 30 per cent. of nickel.

## POWER TRANSMISSION BY DIRECT CURRENT.

**33.** Up to within a comparatively recent date, electric transmission for power purposes was carried out by means of the direct current, alternating current being used when the power was required for lighting purposes only. Later, however, alternating-current motors came into use, and at the present time, large transmission systems use alternating current both for light and power. We will first take up the use of direct current and see what conditions are necessary in order that power may be transmitted to the best advantage.

**34. Dynamos and Motors Used.**—Direct-current dynamos may be either of the constant-current or the constant-potential type. There are but very few power-transmission systems operated by constant-current dynamos, so few that it is not worth while considering such systems. Practically all the current is distributed at constant potential and, in America, compound-wound dynamos are generally used. The motors used in connection with such constant-potential systems are generally of the shunt type, if used for ordinary stationary work, such as driving machinery. If used for railway work, hoisting, mine haulage, etc., they are of the series type. For some kinds of special work, such as running printing presses, elevators, etc., compound-wound motors are used, but such motors are few in number compared with the others.

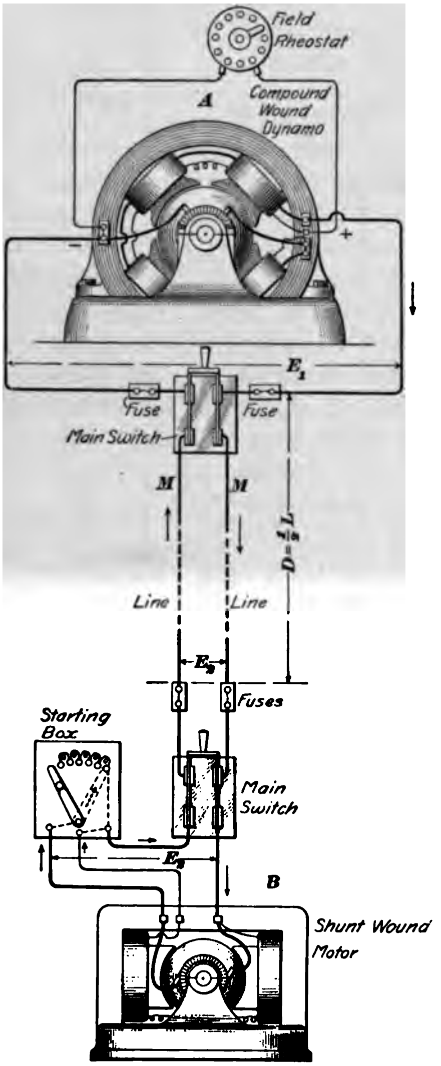

FIG. 11.

**35. Simple Power-Transmission System.** About the simplest possible system of electric-power transmission is that shown in Fig. 11. Here we have a compound-wound dynamo *A* driven by means of an engine not shown. This dynamo sends a current through the motor *B* by means of the lines *M*, *M*. The dynamo is driven at a constant speed and its series winding is adjusted so that the pressure at the terminals of the dynamo rises slightly as the current increases, due to the increase of the load on the motor. This slight rise in voltage is to make up for the loss in pressure in the line, as will be explained later. The pressure at the motor as a whole, however, remains nearly constant, no matter what load the motor may be carrying, but the current supplied increases as the load is increased. Of course, lamps could also be operated on the same system, although it is advisable to have separate circuits for the lamps and motors whenever possible, because if the load on the motor fluctuates, it is apt to cause variations in the lights. When both lights and motors are operated, such a system would probably use a pressure of 110 volts at the receiving end of the circuit; if used for power alone, a pressure of 250 or 500 volts would be employed. It should be mentioned that when the **receiving** end of a circuit is spoken of, the end distant from the station is meant, because this is the end where the various devices, such as lamps, motors, etc., receive their current.

**36. Lost Power and Line Drop.**—In order that a transmission plant may be efficient, the generating apparatus, line, and motors must be efficient. Dynamos and motors of good make are generally satisfactory as regards efficiency, and the question is, how efficient can the line be made? In answer to this, it might be said that the loss of power in the line could be made as small as we please if expense were no consideration. All conductors, no matter how large, offer some resistance to the current and there is bound to be some loss in power. By making the conductor very large we can make the loss small, because the resistance will be low, but a point is soon reached where it pays better to allow a certain amount of power to be lost rather than to further increase the size of the conductor. The pressure necessary to force the current over the line is spoken of in power-transmission work as the **drop** in the line, because this pressure is represented by a falling off in voltage between the dynamo and the distant end of the line.

**37.** If $R$ is the resistance of the line and $C$ the current flowing, the drop is, from Ohm's law, $e = CR$. The power, in watts, lost in the line is $CR \times C = C^2 R$. The power lost, due to the resistance encountered by the current, reappears in the form of heat. The power generated by the dynamo is equal to the product of the pressure generated by the dynamo and the current flowing; or, if $E_1$ represents the dynamo pressure, then

$$\text{Watts generated} = W_1 = E_1 \times C. \qquad \textbf{(3.)}$$

The power delivered at the end of the line is equal to the product of the pressure at the end of the line multiplied by the current, or, if $E_2$ represents the pressure at the distant, or receiving, end, then

$$\text{Watts delivered} = W_2 = E_2 \times C. \qquad \textbf{(4.)}$$

It should be particularly noted at this point that the current $C$ is the same in all parts of the circuit. Thus, in Fig. 11 the same current flows through the motor that flows through the dynamo, unless there is leakage at some point between the lines, and this would not be the case if the lines were properly insulated. What does occur is a drop or loss in pressure between the station and the receiving end, but there is practically no loss in current except, perhaps, in a few cases where the line pressure is exceedingly high or the insulation unusually bad. This point is mentioned here because the mistaken idea that there is a loss of current in the line is a common one.

**38.** We have already seen that the number of watts lost in the line is given by the equation

$$W = C^2 R.$$

The lost power must also be equal to the difference between the power supplied and the power delivered, or

$$\begin{aligned} W &= W_1 - W_2 \\ &= E_1 C - E_2 C \\ &= C(E_1 - E_2). \end{aligned}$$

$E_1 - E_2$ represents the loss of pressure, or the drop, and it is at once seen that the greater the drop, the greater the loss in power. For example, a 5-per-cent. drop in voltage is equivalent to a 5-per-cent. loss of power in the line.

**39.** In order to transmit power, we must be willing, then, to put up with a certain amount of loss, or, what is equivalent, with a certain amount of drop in the line. The amount of drop can be made anything we please, depending on the amount of copper we are willing to put into the line. The percentage of drop allowed is seldom lower than 5 per cent. and not often over 15 per cent.; 10 per cent. is a fair average. In cases where the distribution is local, as, for example, in house wiring, the allowable drop from the point where the current enters to the farthest point on the system may be as low as 1 or 2 per cent. If the drop is excessive, the pressure at the end of the line is apt to fluctuate greatly with changes of load and thus render the service bad. In a few special cases there may be conditions that warrant the use of an excessive drop, but in general the above values are the ones commonly met with.

**40.** When the loss, or drop, in a circuit is given as a percentage, this percentage may refer to the power or voltage at the station end of the line, or the receiving end. For example, suppose we take the case where the percentage loss refers to the power at the station end, and let

$E_1$ = voltage at dynamo;
$E_2$ = voltage at end of line;
$\%$ = percentage loss (expressed as a number, not as a decimal);
$e$ = actual number of volts drop in the line.

Then,
$$E_1 = \frac{100\, E_2}{100 - \%}. \qquad (5.)$$

And
$$e = \frac{100\, E_2}{100 - \%} - E_2. \qquad (6.)$$

**EXAMPLE.**—The voltage at the end of a lighting circuit is to be 110 and the allowable drop is to be 3 per cent. of the dynamo voltage. (*a*) What will be the dynamo voltage? (*b*) What will be the actual drop in volts in the circuit?

**SOLUTION.**— (*a*) We have $E_1 = \frac{100 \times 110}{100 - 3} = 113.4$. Ans.

(*b*) The drop $e = \frac{100 \times 110}{100 - 3} - 110 = 3.4$ volts. Ans.

**41.** It is frequently more convenient to express the loss as a percentage of the power *delivered* at the end of the line. For example, if the voltage at the end of the line were 110, and the loss were to be an amount equivalent to 3 per cent. of *the power delivered*, instead of 3 per cent. of *the power generated*, it would mean that the allowable drop was 3 per cent. of 110, or 3.3 volts, instead of 3.4 volts. Railway generators are commonly spoken of as being adjusted for 10-per-cent. loss when they are so wound as to generate 500 volts at no load and 550 volts at full load; i. e., 50 volts, or 10 per cent., of 500, is allowed as drop in the line, 500 being the voltage at the end of the line. In expressing the loss as a percentage, then, it should be distinctly understood as to whether this percentage refers to the power *generated* or the power *delivered*, otherwise there is liable to be confusion. The best way is to express the drop directly in volts and then there can be no doubt as to what is meant. In what follows, we will, when expressing the loss as a percentage, refer to the power delivered unless it is otherwise specified, as this method is now very generally followed.

## LINE CALCULATIONS.

**42. Calculations for Two-Wire System.**—We are now in a position to look into the method of determining the size of wire necessary for a given case. We will first consider the simple transmission system, shown in Fig. 11. The problem of determining the size of a line wire usually comes up about as follows: Given a certain amount of power to be transmitted over a given distance with a given amount of loss; also, given the required terminal voltage; determine the size of line wire required. The whole problem of determining the size of line wire simply amounts to estimating the size of wire to give such a resistance that the drop will not exceed the specified amount. All the formulas for this purpose are based on Ohm's law, and are simply this law arranged in a little more convenient form to use. There have been a large number of these formulas devised, each for its own special line of work, and the one that is derived below is given because it is as generally applicable as any.

**43.** In the first place, if we are given the watts or horsepower to be delivered and are also given the voltage at the end of the line, we can at once determine the current, because

$$C = \frac{W_2}{E_2}, \qquad (7.)$$

in which $W_2$ is the power delivered. Furthermore, the drop $e$ in the line is known or specified, and since

$$e = CR, \qquad (8.)$$

or

$$R = \frac{e}{C},$$

the resistance $R$ of the line is easily determined.

**44.** Referring to Fig. 11, we see that the total length $L$ of line through which the current flows is twice the distance from the dynamo to the end of the line. It has already been shown that the resistance of a wire is directly proportional to its length and inversely proportional to the area of its cross-section, and we may then say that

$$R = \frac{K \times L}{A},$$

when $K$ is a constant that depends on the units used for expressing the length $L$ and the area of cross-section $A$. In practice, it is generally most convenient to have the length $L$ expressed in feet and the area in circular mils. When these units are used, the quantity $K$ is the resistance of 1 **mil-foot** of wire; i. e., the resistance of 1 foot of wire $\frac{1}{1000}$ inch in diameter. If the area of cross-section of the wire were only 1 circular mil, it is evident that the resistance of $L$ feet of it would be $K \times L$, and if the area of the wire were $A$ circular mils, its resistance would be $\frac{K \times L}{A}$.

The resistance of 1 mil-foot of copper wire such as is used for line work may be taken as 10.8 ohms. This resistance will, of course, vary with the temperature and also with the quality of the wire used, but the above value is close enough for ordinary line calculations. We may then use the following formula for calculating the resistance of any line:

$$R = \frac{10.8 \times L}{A}, \qquad \textbf{(9.)}$$

where $R$ = resistance in ohms;
$L$ = length of line in feet (total length, both ways);
$A$ = area of cross-section in circular mils.

**45.** What we usually wish to obtain is the area of the wire required for the transmission, not the resistance, and by combining formulas **8** and **9**, this can be readily done.

We have $$e = CR,$$

but $$R = \frac{10.8 \times L}{A};$$

hence, $$e = \frac{10.8 \times L \times C}{A},$$

or $$A = \frac{10.8 \times L \times C}{e}. \qquad \textbf{(10.)}$$

Expressing this formula in words, we have the required area of cross-section in circular mils

$$= \frac{10.8 \times \text{length of line in feet} \times \text{current in amperes}}{\text{drop in volts}}$$

This rule for determining the size of wire for a given transmission may be written as follows:

**Rule.**—*Take the continued product of 10.8, the total length of the line in feet, and the current in amperes; divide by the drop in volts, and the result will be the area of cross-section in circular mils.*

**46.** It will be noticed that the size of wire has been determined by making it of such size that the drop will not exceed the allowable amount. In other words, the drop has been made the determining factor and no attention has been paid to the current-carrying capacity of the wire. If the distance were very short and the drop allowed were large, the size of wire as given by the formula might be such that it would not carry the current without greatly overheating. This is an important consideration where wires are run indoors, because the distances are then short and the rise in temperature of the wire needs to be carefully considered, owing to the fire risk. This point will be taken up in connection with interior wiring. For line work such as we are now considering, the distances are usually so large that the size of wire as determined by the allowable drop is nearly always much larger than would be called for simply to carry the current without becoming hot enough to do damage.

**47.** The formula given above is also often written in the form

$$A = \frac{21.6 \times D \times C}{e}, \qquad \textbf{(11.)}$$

where $D$ is the distance (one way) from the station to the center where the power is delivered. Evidently, $D$ is only one-half the length of line through which the current flows, i. e., $L = 2\,D$; hence, we double the constant 10.8 and use 21.6 in the formula.

**48.** Formulas **10** and **11** may be applied to a large number of cases if care is taken to see that the proper values are substituted in them. The length $L$ or distance $D$ *must always be expressed in feet.* The use of the formula will be illustrated in connection with the following examples:

EXAMPLE 1.—In Fig. 11. the pressure at the receiving end of the line is to be 500 volts, and 40 kilowatts are to be transmitted with a drop of 50 volts. The distance from the station to the end of the line is 3 miles. Calculate the cross-section of wire necessary and give the nearest size B. & S. that will answer.

SOLUTION.— 40 kilowatts = 40,000 watts; hence, current $= \frac{40,000}{500}$ = 80 amperes. The distance from the station to the end of the line is 3 miles, but the current has to flow to the end and back again, so that the length of line $L$ through which the current flows is 6 miles, or 31,680 feet. Applying formula **10,** we then have

$$A = \frac{10.8 \times 31,680 \times 80}{50}$$
$$= 547,430 \text{ circular mils, nearly. Ans.}$$

This is considerably larger than any of the B. & S. sizes, so that a stranded cable would be used.

EXAMPLE 2.—It is desired to transmit 20 horsepower over a line ½ mile long with a drop of 10 per cent. of the voltage at the receiving end. The voltage at the end of the line is to be 110. Find the size of wire required.

SOLUTION.— 20 horsepower = 20 × 746 watts, and, hence,

$$\text{Current} = \frac{20 \times 746}{110} = 135.6 \text{ amperes.}$$

The drop is to be 10 per cent. of the voltage at the receiving end; hence,

$$\text{Drop } e = \frac{110 \times 10}{100} = 11 \text{ volts.}$$

The length $L$ is 1 mile, since the distance from the station to the end is ½ mile, and applying formula **10,** we have

$$A = \frac{10.8 \times 5,280 \times 135.6}{11} = 702,950 \text{ circular mils, nearly. Ans.}$$

This also would call for a large cable.

EXAMPLE 3.—Fig. 12 shows a simple transmission system as used in connection with a street railway. The feeder $a\,c$ runs out from the station and taps into the trolley wire $x\,y$ at the point $c$. The pressure between the trolley and track at the point $c$ is to be 500 volts, and the loss *in the feeder* is to be 10 per cent. of the voltage at the car when a current of 60 amperes is being supplied. The current returns through the track, and we will suppose in this case that the resistance of the return circuit is negligible. Required the cross-section of the feeder $a\,c$.

SOLUTION.—In this case the drop takes place altogether in the wire $a\,c$, because the resistance of the return circuit through the rails is taken as zero; hence, the length $L$ used in the formula will be $\frac{3}{4}$ mile, or 3,960 feet, and not twice this distance, as in the previous examples. The drop in voltage will be

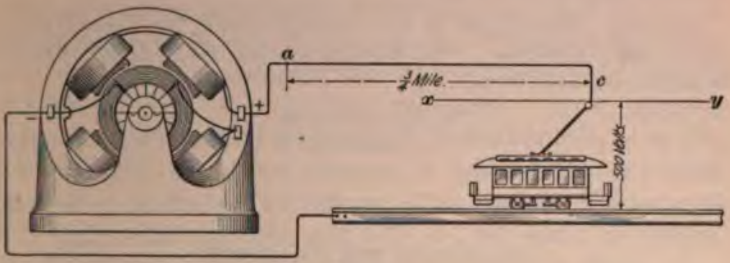

FIG. 12.

$$e = \frac{500 \times 10}{100} = 50,$$

and since the current is 60 amperes, we have

$$A = \frac{10.8 \times 3{,}960 \times 60}{50} = 51{,}322 \text{ circular mils. Ans.}$$

Referring to the wire table, we find that this is nearly a No. 3 B. & S.

**49.** In making line calculations, it seldom happens that the calculated value will agree exactly with any of the sizes given in the wire table. It is usual in such cases to take the next larger size, unless the smaller size should be considerably nearer the calculated value. Generally, the load operated on a line always tends to increase, because business increases, and it is better to have the line a little large, even if it entails a slightly greater cost when the line is erected.

**50.** Formula **10** may also be used for determining the drop that will occur on a given line with a given current. In this case the formula is written

$$\text{Volts drop} = e = \frac{10.8 \times L \times C}{A}. \qquad \textbf{(12.)}$$

**Example.**—Power is transmitted over a No. 3 B. & S. line for a distance of 4,000 feet. What will be the drop in the line when a current of 30 amperes is flowing?

**Solution.**—The length of wire through which the current flows is 2 × 4,000 = 8,000 feet. The cross-section of a No. 3 B. & S. wire is 52,634 circular mils; hence,

$$\text{Volts drop} = \frac{10.8 \times 8{,}000 \times 30}{52{,}634} = 49.2. \quad \text{Ans.}$$

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### EXAMPLES FOR PRACTICE.

1. A dynamo delivers current to a motor situated 850 yards distant. The current taken by the motor at full load is 30 amperes, and the pressure at the motor is to be 220 volts. The drop in the line is to be 8 per cent. of the voltage at the receiving end. Required (*a*) the drop in volts; (*b*) the size of the wire in circular mils and also the nearest size B. & S.

Ans. (*a*) 17.60 volts.
(*b*) 93,886 cir. mils., No. 1 wire.

2. A current of 40 amperes is transmitted from a station to a point 1 mile distant through a No. 0 B. & S. wire. (*a*) What will be the drop in volts in the wire? (*b*) How many watts will be wasted in the wire?

Ans. (*a*) 43.2.
(*b*) 1,728.

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### USE OF HIGH PRESSURE.

**51.** By referring to the first two examples of Art. **48**, it will be noticed that the wire called for is very large, although the amount of power transmitted is not very great nor the distances long. Suppose we have a fixed number of watts $W'_2$ to transmit with a given voltage $E_2$ at the end of the line; then, the current that must flow through the line is $\frac{W'_2}{E_2}$. Also, we have already seen in Art. **37** that the loss in the line is $C^2 R$; i. e., if the current be doubled the loss becomes 4 times as great. If we can double the E. M. F., we will be able to transmit the same amount of power with one-half the current, and, hence, with one-quarter the loss. Or, if we put it the other way, and suppose that our loss is to be a fixed amount, we can, by doubling the pressure and thereby halving the current, use a wire of 4 times the resistance. For example, suppose we have to transmit 20 kilowatts at a terminal pressure of 500 volts and that the loss in the line is to be limited to 2 kilowatts. The current would be $C = \frac{20000}{500} = 40$ amperes, and $C^2R = 2{,}000$ watts, or $40^2R = 2{,}000$; hence, $R = \frac{2000}{1600} = 1.25$ ohms. Now, suppose that we use a terminal pressure of 1,000 volts instead of 500, and transmit the same amount of power with the same number of watts loss as before. The current will now be $C = \frac{20000}{1000} = 20$ amperes, and $C^2R = 2{,}000$ watts, as before. We will then have $20^2R = 2{,}000$; $R = \frac{2000}{400} = 5$ ohms.

In other words, *for the same amount of loss and for the same amount of power delivered, the allowable resistance of the line is made four times as great by doubling the pressure.* Since the length is supposed to be the same in both cases, this means that doubling the pressure makes the amount of copper required just one-fourth as great. If the pressure were increased threefold, the amount of copper required would be one-ninth as great, other things being kept equal, as before. This may be stated as follows: *For the same amount of power delivered and for the same amount of loss, the amount of copper required for transmission over a given distance varies inversely as the square of the voltage.*

**52. Edison Three-Wire System.**—From the preceding it will at once be seen that an increase in the voltage results in a large decrease in the amount of copper required. Incandescent lighting was first carried out at a pressure of 110 volts, but this pressure rendered the use of large conductors necessary, and systems were, therefore, brought out that would permit the use of a higher pressure. In street-railway work, a pressure of about 500 volts soon became the standard, because this appeared to be the limit to which the voltage could be pushed for this class of work without danger to life.

The Edison **three-wire system** allows current to be supplied at 110 volts, although the transmission itself is really carried out at 220 volts, and, therefore, results in a large saving in copper over the old 110-volt system. The three-wire system is shown in Fig. 13. Two compound-wound dynamos *A* and *B* are connected in series across the two lines *d e* and *h k*. Each dynamo generates 110 volts, so that the pressure between the two outside wires is 220 volts, because the two machines are connected in series, and their pressures will be added. A third wire, called the ***neutral wire***, is connected to the point *f* between the machines, so that between the lines *d e* and *f g* we have a pressure of 110 volts, and between *f g* and *h k* a pressure of 110 volts also.

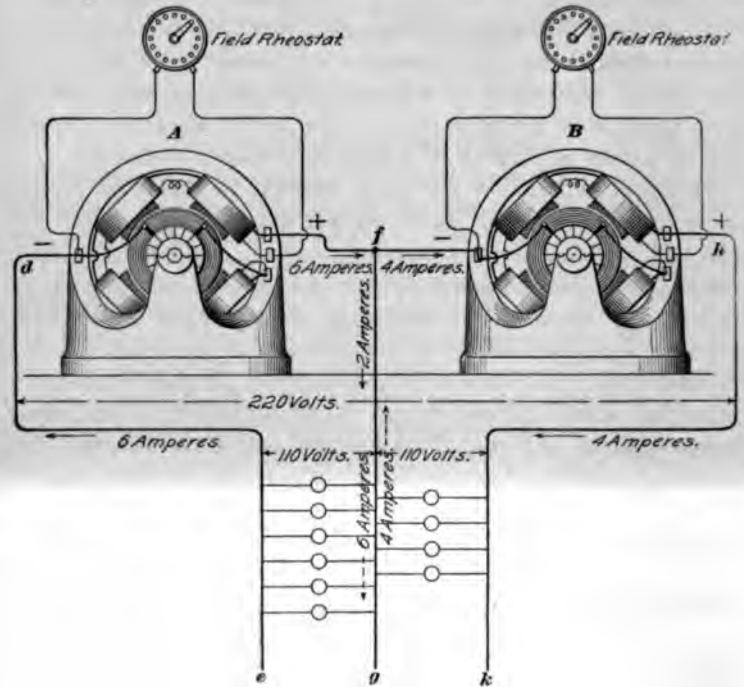

FIG. 13.

**53.** In order to illustrate the action of such a system, we will suppose that we have six 32-candlepower lamps on one side and four on the other, each lamp taking, say, 1 ampere. A current of 4 amperes will flow from the positive side of *B* through the line *h k* and through the lamps to the neutral wire. At the same time, a current of 6 amperes will tend to flow out from the positive pole of *A* over the line *f g* through the left-hand set of lamps and back through *e d*, as shown by the arrows. In the neutral wire we have a current of 6 amperes tending to flow in one direction and a current of 4 amperes tending to flow in the other direction, the result being that the actual current is the difference between the two, or 2 amperes, as shown by the full arrow; or, looking at it in another way, we have 4 amperes flowing directly across from *h k* to *d e* and 2 amperes flowing from *A* through the neutral wire *f g* and back through *e d* to *A*, thus making 6 amperes in the line *e d*. If the currents taken by the two sides were exactly balanced, no current would flow in the neutral wire and we would have what is practically a 220-volt two-wire transmission. In any case, the current in the neutral wire is the difference between the currents in the two sides, and its direction will depend on which side is the more heavily loaded.

**54.** A three-wire system should always be installed so that the load on the two sides will be as nearly balanced as possible. The simplest way to estimate the size of the conductors is to first calculate the size of the outside wires, treating it as if it were a 220-volt two-wire system. When motors are operated on the three-wire system, they are usually wound for 220 volts and connected across the outside lines. The following example will illustrate the method of calculating the wires for a three-wire transmission:

EXAMPLE.—Two dynamos deliver power over a distance of 1 mile to sixty 32-candlepower lamps, thirty lamps on each side of the circuit, as shown in Fig. 14. A motor that requires a current of 40 amperes is also connected across the outside wires. Each lamp requires a current of 1 ampere, and the pressure at the lamps is to be 110 volts. Calculate the size of wire required for the two outside conductors if the drop in pressure is not to exceed 10 per cent. of the voltage at the end where the power is delivered.

Sol 'he first thing to determine is the current. Thirty lamps ected on each side and these lamps are connected in mul aking 1 ampere. The current, therefore, in the outside s to the lamps is 30 amperes. The motor is connected

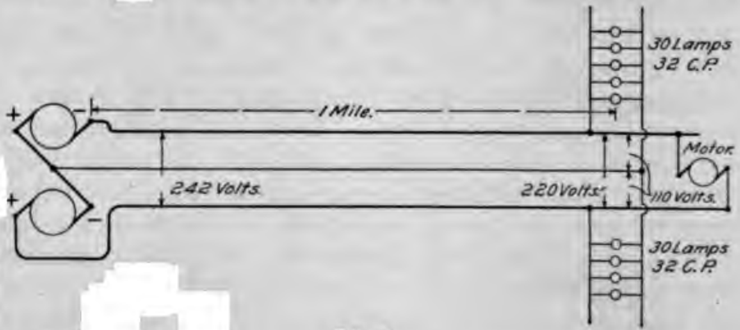

FIG. 14.

s the outside lines; hence, the current due to the motor and the total current in the outside lines is 70 amperes. re across the outside wires must be 220 volts at the end of the line, because the pressure at the lamps is to be 110. The drop in outside wires is, therefore,

$$220 \times .10 = 22 \text{ volts.}$$

The length of the outside wires is 2 miles, or 10,560 feet. Applying formula **10**, we have

$$\text{Circular mils} = \frac{10.8 \times 10{,}560 \times 70}{22} = 362{,}880. \quad \text{Ans.}$$

This would require a stranded cable.

**55.** The neutral wire is often made one-half the cross-section of the outside wires, though practice differs in this respect. It is seldom, however, made less than one-half, and in a number of cases it is made equal in cross-section. Of course, if the load could be kept very nearly balanced at all times, a small neutral wire would be sufficient, but it is impossible to keep the load balanced, and, hence, it is usual to put in a neutral of at least one-half the cross-section of the outside wires. In the above example, a No. 000 wire would probably be large enough for the neutral wire. For distributing mains, when there is much liability to unbalancing, the neutral is made equal in size to the outside wires.

In some cases, three-wire systems are arranged so that they can be changed to a two-wire system by connecting the two outside wires together to form one side of the circuit, the neutral wire constituting the other side. If this is done, the neutral would have to carry double the current in the outside wires and would be made twice as large as the outside wires.

**56.** Since the outside wires are only $\frac{1}{4}$ the size required for the same power delivered by means of the two-wire 110-volt system with the same percentage of loss, it follows that, even if the neutral wire be made as large as the outside wires, the total amount of copper required is only $\frac{1}{4} + \frac{1}{8}$, or $\frac{3}{8}$ of that required for the two-wire 110-volt system. The amount of copper in the neutral wire is only $\frac{1}{8}$ that which would be required for the two-wire system, because it is only $\frac{1}{4}$ the cross-section and its total length is only $\frac{1}{2}$ that required for the two-wire system.

**57.** From the preceding it will be seen that the three-wire system of distribution effects a considerable saving in copper, owing to the use of a higher pressure. Three-wire systems operating 220-volt lamps with 440 volts across the outside wires have been introduced with considerable success, thus making a still further reduction in copper. The tendency has naturally been to use as high pressures as possible, but there are grave difficulties in the way of transmitting current at high pressure by means of direct current. These difficulties may be classed under the heads (*a*) difficulty of generating direct current at high E. M. F.; and (*b*) difficulty of utilizing direct current at high pressure after it has been generated.

**58.** Machines for the generation of direct current must be provided with a commutator, and this part of a well-designed machine gives comparatively little trouble if the pressure generated does not exceed 700 or 800 volts. If the pressure is increased beyond this amount, it becomes a difficult matter to make a machine that will operate without sparking. Moreover, in direct-current dynamos, the armature winding has to be divided into a large number of sections or coils, and the numerous crossings of these coils make it exceedingly difficult to insulate such armatures for high pressures.

**59.** Even if it were possible to generate high-pressure direct current, it would be difficult to utilize it at the other end on account of the danger to life.. About 500 volts is as high as it has been found safe to operate street railways, the consideration of safety setting this limit on the pressure used. Moreover, it is just as difficult to build motors for high-pressure direct current as it is dynamos, and for most purposes the high-pressure current would have to be reduced to low pressure before it could be utilized with safety at the distant end of the line. This transformation could be effected by using a high-voltage motor to drive a low-voltage dynamo. In some cases, these two machines might be combined into one having an armature provided with two windings and two commutators, this armature being arranged so as to revolve in a common field magnet. The high-tension current from the line is here led into one winding through one commutator and drives the machine as a motor. The second set of windings connected to the other commutator cuts across the field and sets up the secondary E. M. F., thus applying current to the low-pressure lines. A machine of this kind is known as a **dynamotor.** It is thus seen that the transformation of direct current from high pressure to low pressure involves the use of what is essentially a high-pressure direct-current motor—a piece of machinery that is liable to give more or less trouble for the reasons already given.

## POWER TRANSMISSION BY ALTERNATING CURRENT.

**60.** The difficulties connected with the generation and utilization of high-tension direct current led engineers to adopt alternating current for places where the power had to be transmitted over considerable distances. At first, alternating current was used for lighting work only, because the single-phase alternators first introduced were not capable of readily operating motors, although they were quite satisfactory for the operation of incandescent lamps. With the introduction of multiphase alternators along with the induction motor, the use of alternating current for power purposes became very common, and plants using line pressures as high as 40,000 volts, or even higher, are now in use.

**61.** The alternating current is well adapted for high-pressure work, because not only can it easily be generated, but what is even of greater importance, it can be readily transformed from one pressure to another by means of transformers. The winding of an alternator armature is very simple, no commutator is necessary, and the problem of generating high pressures becomes a comparatively simple one. Alternators with stationary armatures have been successfully built for pressures as high as 10,000 or 12,000 volts. In some cases, the current is generated at a comparatively low pressure and raised by step-up transformers for transmission over the line. At the distant end it is easily lowered, by means of step-down transformers, to any pressure required for the work to which it is to be put.

## SINGLE-PHASE TRANSMISSION.

**62.** The simplest scheme for alternating-current power transmission is that which uses a single-phase dynamo, i. e., a machine that generates a single alternating current. In Fig. 15, *A* represents a simple alternator that generates current at high pressure. This current is transmitted over the line to the distant end, where it is sent through the primary of transformer *B*, which lowers the pressure to an amount suitable for distribution to the lamps *l*. The synchronous motor *M* is operated directly from the line, because it can be wound for a high voltage. If, however, this high pressure about the motor should for any reason be objectionable, step-down transformers could be used. As already

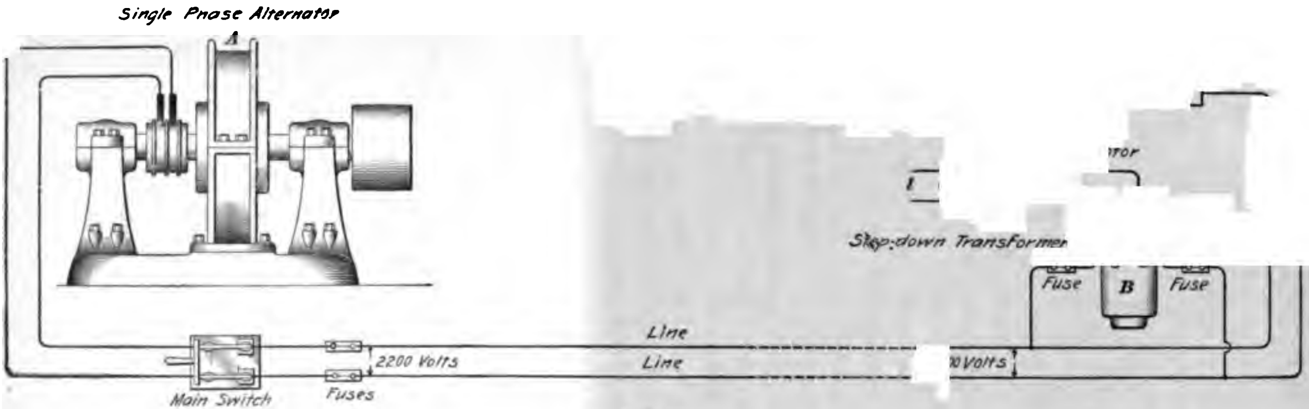
Single Phase Alternator
A
ator
Step-down Transformer
Fuse
B
Fuse
Line
Line
2200 Volts
0 Volts
Main Switch
Fuses

FIG. 15.

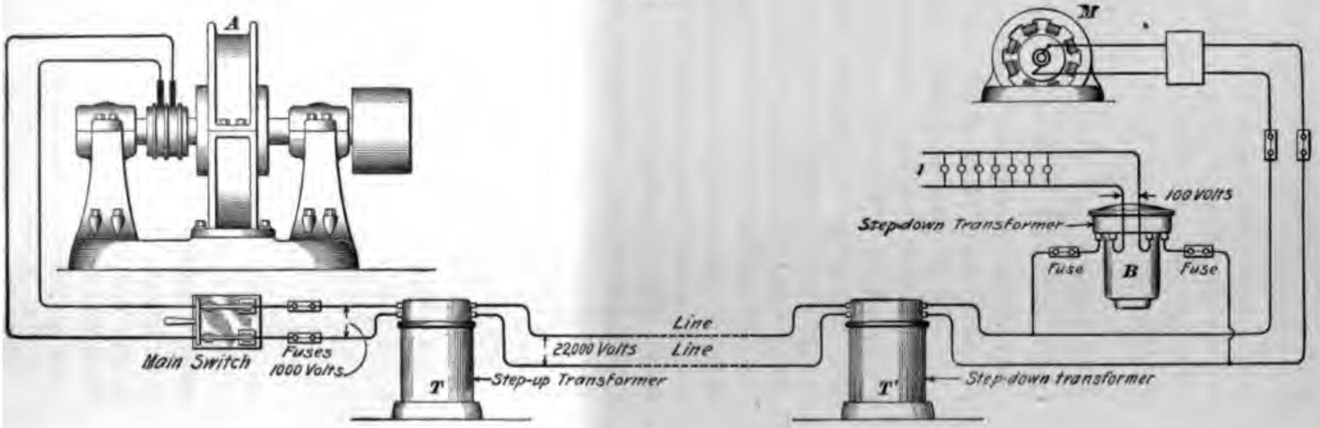
A
M
100 Volts
Step-down Transformer
Fuse
B
Fuse
Main Switch
Fuses
1000 Volts
T
Step-up Transformer
22000 Volts
Line
Line
T'
Step-down transformer

FIG. 16.

mentioned, such systems are installed for lighting work almost exclusively, because the single-phase alternating current is not well adapted for the operation of motors. At first a pressure of 1,100 volts at the alternator, or about 1,000 at the end of the line, was commonly used. Later, pressures of 2,200 and 2,000 volts became the ordinary practice. In cases where the distance was very long, step-up transformers were used, as shown in Fig. 16. Here the current from the alternator *A* is first sent into the primary of the transformer *T*, which raises the voltage to any required amount, with, of course, a corresponding reduction in current. The alternator might, for example, generate a pressure of 1,000 volts and this pressure be raised to 22,000 for transmission over the line. At the other end, the transformer *T'* steps down the high line pressure to whatever pressure is suitable for the local distribution. The single-phase alternating-current system is in many respects similar to the two-wire direct-current system, the principal distinguishing feature being the use of transformers.

**63.** The single-phase system has been used in the past to a limited extent for the operation of synchronous motors. The ordinary single-phase synchronous motor, i. e., a motor constructed in the same way as an alternator, will not start up even if it is not loaded; it has to be brought up to speed from some outside source; this is a great drawback to its use, and the single-phase system is now seldom, if ever, installed where power is to be transmitted for the operation of alternating-current motors of large size. The motor *M* shown in Fig. 15 is the same in construction as an alternator, but it would have to be provided with some arrangement for bringing it up to speed. This could be done by means of a small single-phase induction motor or by using the exciter of the synchronous motor, running it as a motor from storage batteries. This difficulty of getting single-phase synchronous motors started has kept them from being used to any great extent, and even in those places where they were installed, they are being replaced by multiphase synchronous

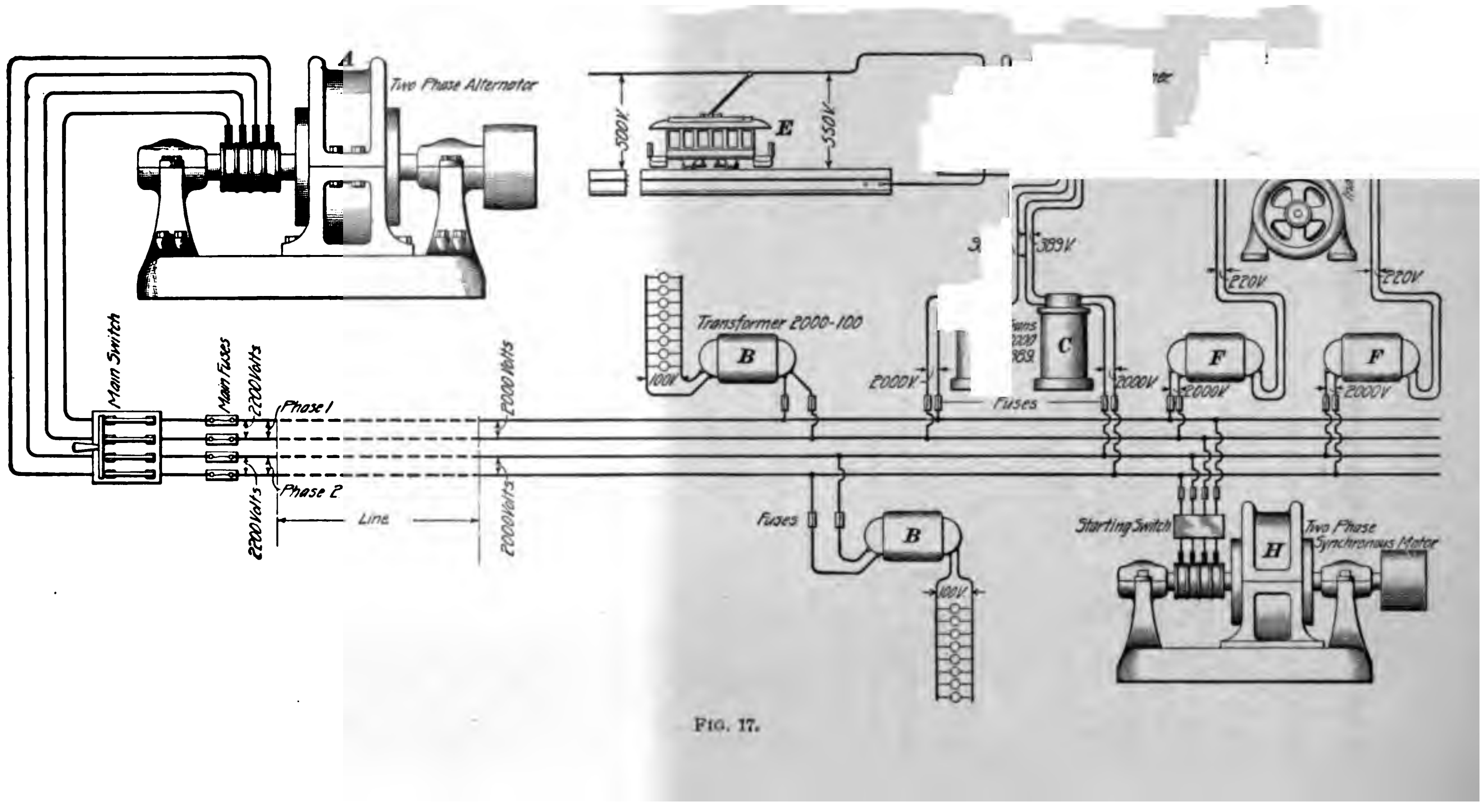
A
Two Phase Alternator
500V
E
550V
389V
220V
220V
Transformer 2000-100
B
100V
2000V
C
2000V
F
2000V
F
2000V
Fuses
Main Switch
Main Fuses
2200 Volts
Phase 1
2000 Volts
Phase 2
2200 Volts
Line
2000 Volts
Fuses
B
100V
Starting Switch
H
Two Phase Synchronous Motor

FIG. 17.

motors, which will run up to speed of their own accord when not loaded.

If the amount of power required is not large, say under 10 horsepower, special self-starting single-phase synchronous motors may be used. Induction motors are also made to operate on single-phase circuits by using special starting devices, but in general it may be stated that the single-phase system is not well adapted for motor operation, at least not in those cases where large motors are required.

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## TWO-PHASE POWER TRANSMISSION.

**64.** A two-phase alternator delivers two currents differing in phase by 90°, so that when the current in one phase is at its maximum value, the current in the other phase is at zero. The great advantage of the two-phase system over the single-phase is that it allows the operation of rotary-field induction motors and two-phase synchronous motors. Two-phase induction motors will start up under full load. The synchronous motors will not start up under load, but they will run up to synchronous speed if they are not loaded, and the load can be thrown on afterwards, thus avoiding the necessity of any outside means of bringing the machines up to synchronism. Lights may, of course, be operated on the two-phase system equally as well as on the single-phase.

**65.** Fig. 17 shows a two-phase system. In this case, we have taken the simplest arrangement, where the alternator feeds directly into the line without the use of step-up transformers. If, however, the distance is very long, a pair of step-up transformers could be connected at each end, one in each phase, in a manner similar to that shown in Fig. 16. We have taken the line pressure at 2,000 volts for the sake of illustration. *A* is the alternator supplying the two currents differing in phase by 90° to the four line wires. The only difference between this alternator and a single-phase machine lies in its armature winding and the addition of two more collector rings. *B*, *B* are two transformers supplying lights.

One is [illegible] ed on Phase No. *1* and the other on Phase No. *2*, so as [illegible] to unbalance the load on the alternator. *C*, *C* are two large transformers supplying alternating current at 389 volts to the rotary transformer *D*, which changes it to direct current at 550 volts suitable for operating the street-railway system *E*.

The alternating-current voltage of a two-phase rotary is 707 times the direct-current voltage. If, then, a voltage for erating the street railway is to be 550 volts, the trans- mers must supply 550 × .707 = 389 volts, nearly, to the lternating-current side of the rotary. *F*, *F* are two transformers supplying a two-phase induction motor *G*. As stated above, this type of motor is capable of starting up under full load, and, generally speaking, may be used for all ds of stationary work for which the ordinary direct-cur- t motor is adapted. *H* shows a two-phase synchronous otor. This is the same in construction as the generator *A*, nd it is not necessary to use transformers with it, as it can e constructed for the same voltage as the generator. ynchronous two-phase motors are well adapted for places here power is required in fairly large units and where the motor does not have to be started and stopped frequently. They do not, if properly handled, set up lagging currents; i. e., currents that lag behind the E. M. F., and, hence, are out of phase with the E. M. F. The nature and disadvantages of these lagging currents will be explained more fully in connection with the calculation of lines for alternating current. If synchronous motors and induction motors are operated on the same system as shown in Fig. 17, the lagging current set up by the induction motor may be neutralized by the synchronous motor by increasing the field excitation of the latter to the proper amount. The ordinary method of connecting up transformers on a two-phase circuit is that shown in Fig. 17. Other methods are sometimes used, but these will be taken up later when transformer connections are discussed. In some cases, three line wires only are used, but otherwise the connections are the same as shown in Fig. 17.

## THREE-PHASE POWER TRANSMISSION.

**66.** In the three-phase system, three currents differing in phase by 120°, or one-third a complete cycle, are employed. If the load on all three phases is kept nearly balanced, as it usually is in practice, only three wires are needed. For the same amount of power, line loss, and distance of transmission, the three-phase system requires only three-fourths the amount of copper called for by the single-phase or two-phase system. For this reason, it is often used for the transmission itself, even if the power is generated by means of two-phase alternators. By a special arrangement of transformers, which will be described later, two currents differing in phase by 90° can be transformed into three differing in phase by 120°. Fig. 18 is similar to Fig. 17, except that it is arranged for a three-phase transmission. Lights, rotary transformers, induction motors, and synchronous motors may be operated as previously described, and all the advantages that have been noted with reference to two-phase motors apply equally to three-phase motors. There is little choice between the two-phase systems so far as actual operation is concerned, the chief point in favor of the three-phase system being the saving in line wire.

**67. Substations.**—In many large transmission systems, it is customary to generate the power in one large central station and distribute it at high pressure to a number of *substations* located at the various distributing centers. At these substations the current is transformed down and passed through rotary transformers, if direct current is necessary, and distributed to the various devices to be operated. This is commonly done in connection with both lighting and street-railway work. If alternating current alone is used, the voltage is merely stepped down by means of large transformers. Perhaps one of the best examples of three-phase transmission is that of the Metropolitan Street Railway Company, of New York. Most of the surface cars in New York City are operated by direct current, at 500 to 600 volts, supplied to the cars by means of conductors placed in a conduit

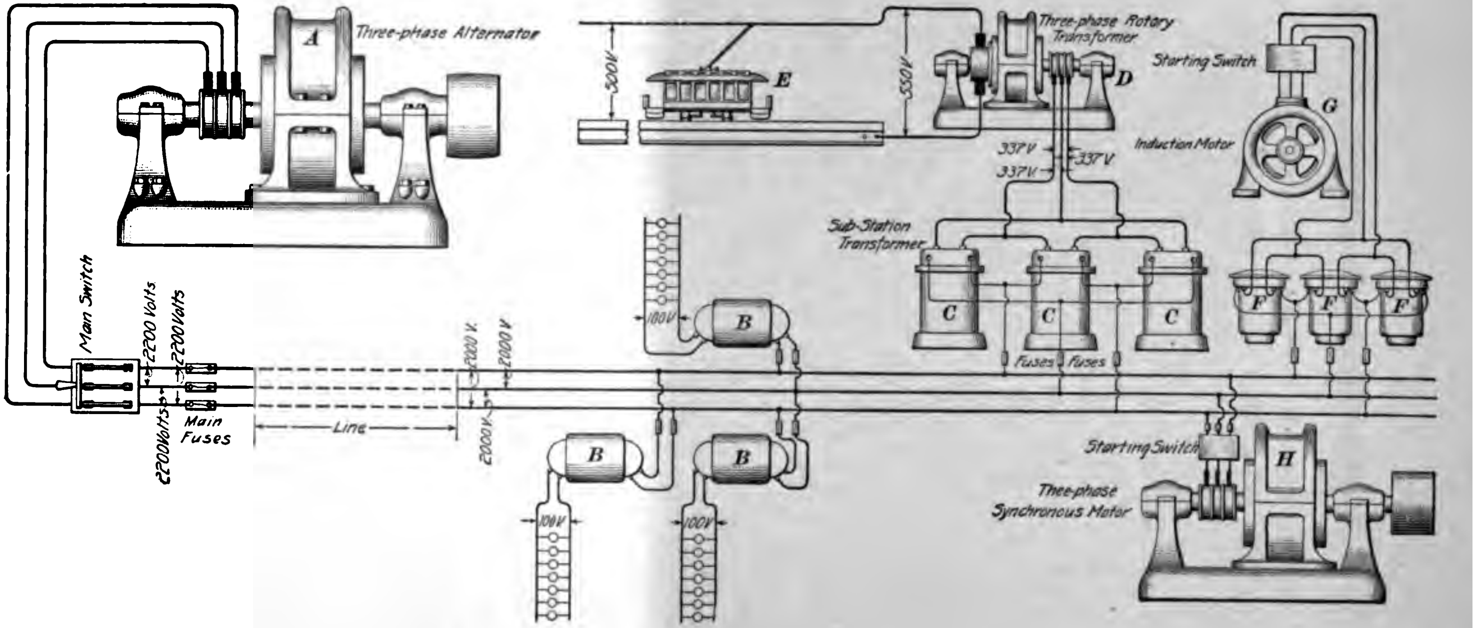
A
Three-phase Alternator
Main Switch
2200 Volts
2200 Volts
2200 Volts
Main
Fuses
Line
2000 V.
2000 V
2000 V
500V
E
550V
Three-phase Rotary
Transformer
D
337V
337V
337V
Sub-Station
Transformer
C
C
C
Fuses
Fuses
Starting Switch
G
Induction Motor
F
F
F
B
B
B
100V
100V
100V
Starting Switch
H
Thee-phase
Synchronous Motor

FIG. 18.

between the rails. Power is generated at one large central station located on the river front, where coal and water are easily supplied. Large 3,500-kilowatt three-phase generators are located in this station. They are of the revolving-field type and are driven directly by large, vertical Corliss engines. These machines generate current at a pressure of 6,600 volts, so that no step-up transformers are used. The current is led from the main station by means of lead-covered underground cables to a number of substations located in different parts of the city. These substations contain the step-down transformers and rotary transformers that are necessary to convert the three-phase current into a direct current of 500 volts suitable for operating the street cars. Each of the rotary transformers is of 900 kilowatts capacity, and before sending the current into rotaries, it is transformed to six phases, as the increased number of phases makes the output of the rotary for a given size of machine greater. Otherwise, the arrangement in the substations is very much the same in principle as that shown at *C* and *D*, Fig. 18. In addition to the rotaries and transformers, such substations are usually provided with two switchboards, one for the high-tension side and the other for the low-tension side, from which the power is distributed. When three-phase rotaries are used, they must be supplied with alternating current at a voltage about .612 times that of the continuous current which they are to supply. For example, in Fig. 18, if the rotary *D* supplies 550 volts direct current, the transformer *C* must supply current at 550 × .612 = 337 volts, nearly, to the alternating-current side of the rotaries.

**68. Frequencies.**—Where motors are operated by alternating current, the frequency used is seldom above 60, although frequencies as high as 125 have been used to a slight extent. A frequency of 60 is very largely used where both lights and motors are operated. Where the current is used for power purposes alone, lower frequencies are common; for example, both the Niagara plant and the plant of the Metropolitan Street Railway Company, referred to above, use a frequency of 25, as a low frequency is better adapted for the operation of rotary transformers than a high frequency.

## TRANSFORMERS AND TRANSFORMER CONNECTIONS.

**69.** The use of transformers has frequently been mentioned in connection with the preceding articles and their action has already been explained. It will be well, however, to take up here some points relating more particularly to their operation and connections.

**70.** Transformers vary somewhat as to their construction, but they all have the three essential parts, i. e., the primary and secondary coils or groups of coils and the iron core that serves to carry the magnetic flux through the coils. Their construction also depends to some extent on whether they are to be used outdoors or indoors. Fig. 19 shows a typical transformer for outdoor use mounted on a pole in the usual manner. Where transformers are large, say above 25 or 30 kilowatts capacity, it is not advisable to mount them on poles if it is possible to avoid it. For this reason, large transformers are usually of the indoor type. There is no need of providing weather-proof cases for such transformers, and their construction is very frequently quite open. Most modern transformers for outdoor use are now built so that the case may be filled with oil. This improves the insulation, keeps out moisture, and has considerable effect on the temperature that the transformer attains while in operation. There is bound to be a certain amount of loss in every transformer, owing to the resistance of the coils and the resistance that the core offers to the changing magnetism, i. e., owing to the hysteresis loss. These losses all reappear in the form of heat, and this heat must be gotten rid of by radiation. If there is an air space between the coils and the iron case of the transformer, the heat is conducted away with difficulty;

but if the case is filled with oil, the oil circulates more or less and serves as a conducting medium for carrying the heat from the coils and core to the case, where it is radiated to the surrounding air. Very often, when the transformers are large, they are unable to get rid of the heat by radiation alone, without becoming so hot that there is danger of damaging the insulation, and it is necessary to provide some artificial means for cooling them. This is usually accomplished either by mounting the transformer so that air may be circulated through it by means of fans or by immersing the transformer in oil, which is kept cool by water circulating in coiled pipes. As stated above, these precautions are only necessary in the case of large transformers, such as those used in substations. Transformers of ordinary size, such as are placed on poles, are able to get rid of the heat generated without any special cooling devices, because the area exposed to the air is much larger in proportion to the output in the case of a small transformer than in the case of a large transformer.

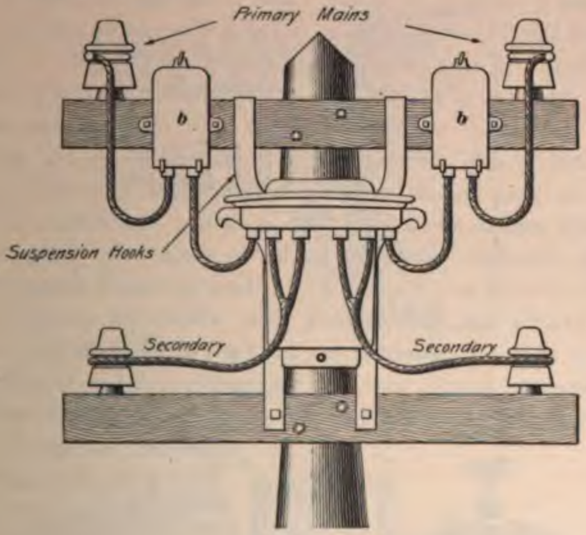

FIG. 19.

**71. Primary Fuses.**—Transformers are operated on constant-potential circuits almost exclusively; hence, if a short circuit occurs on either primary or secondary, there will be a heavy rush of current, which will do damage unless the transformer is instantly disconnected from the circuit. This is accomplished by inserting fuses in the primary between the transformer and the line. These fuses are contained in the fuse boxes *b*, *b*, Fig. 19. They also protect the transformer against overloads, because, if the secondary current is more than it should be, the primary current will also exceed the allowable amount and the fuses will blow. Fuses should be placed in each side of the primary and they should be so mounted that they may be easily replaced by the lineman. In order to accomplish this, nearly all modern primary fuse blocks are made so that the fuse holder may be entirely disconnected from the primary mains when the fuse is being renewed. In other words, the fuse block is made to serve the purpose of a switch as well as a fuse holder. In some cases these primary fuse blocks are double-pole, but when the primary pressure is high, it is better to use two single-pole fuse blocks. Double-pole blocks are not recommended for transformers of larger capacity than 2,500 watts. Above this size it is better to use a single block in each side.

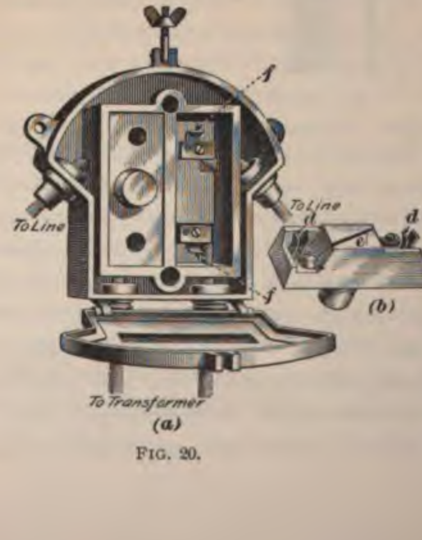

FIG. 20.

**72.** Fig. 20 (*a*) shows a General Electric double-pole primary switch and fuse block, with one fuse holder (*b*) removed for replacing a fuse. The fuse lies in a deep slot *e* in the porcelain holder (*b*), and is fastened to the clips *d*, *d*. When the holder is in place, the clips *d*, *d* engage with the terminals *f*, *f*, thus completing the connection to the transformer primary. When a fuse is to be renewed, the porcelain base is pulled out and the lineman can replace the fuse without danger.

**73.** Fig. 21 shows a single-pole block made by the Stanley Company. In this case, the lid of the iron box is placed at the bottom and the fuse holder *A* is pulled out, thus breaking connection with the terminals *f*, *f*. The fuse *g* runs through a block of wood *h*, thus confining the arc and preventing it from arcing and burning the terminals *t*, *t*. Fig. 21 (*b*) shows the box closed and in the position in which it is placed on the pole. In the General Electric single-pole primary cut-out, the wires enter at the bottom, as shown in

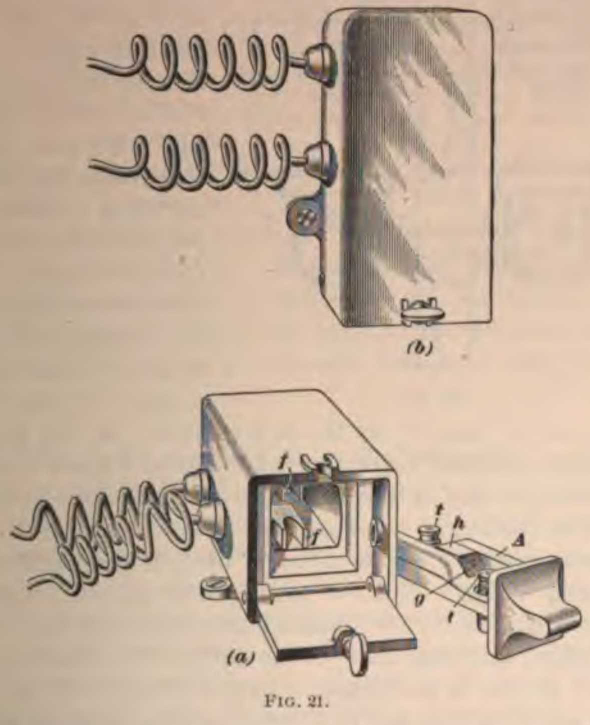

FIG. 21.

Fig. 19. Where large transformers are operated in substations, automatic switches or circuit-breakers are used instead of fuses to disconnect the transformer from the line in case of a short circuit or overload.

## TRANSFORMERS ON SINGLE-PHASE CIRCUITS.

**74. Transformers in Parallel.**—Transformers may be connected in parallel so as to feed a single circuit, as shown in Fig. 22, but care must be taken in connecting them up, or else a short circuit may result. We will suppose that the two transformers to be connected in parallel are of the same type, so that they will both be wound alike. The primary terminals $P_1$ and $P_3$ must be connected to the same main, and $P_2$ and $P_4$ to the other main. If this is done, then the secondary terminals *a* and *c*, and *b* and *d* will have the same polarity at the same instant, and these terminals should be connected together, as shown. The external circuit, consisting of lamps or other load, is connected to the secondary mains. Now, it will be noticed that, from the way in which the two secondaries are connected, they oppose each other, and that little or no current will flow until the outside circuit is connected. In practice, it will be found that a small current will flow between the transformers, but this current will not be at all large. Suppose, however, that the secondary terminals should be connected as shown in Fig. 23; it will be seen that the two secondary coils are here connected in series so that the E. M. F.'s generated in them act together to set up a current through the coils,

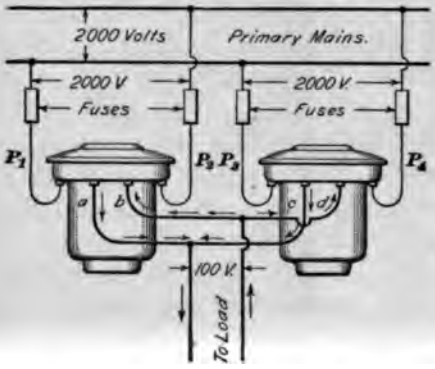

FIG. 22.

thus resulting in a short circuit. In connecting up the secondaries, before making the final connections and before connecting on the circuit, it is always well to make sure that the proper secondary terminals are being connected together. This can be found out by connecting two of them together and then connecting the other two through a piece of small fuse wire or fine copper wire. If the fuse blows, it shows that the connections should be reversed. It is often more convenient to reverse the primary terminals than the secondary, especially if the latter have been joined up permanently. Reversing the primary has, of course, the same effect as reversing the secondary, and it is usually easier to carry out, because the primary connections are light and easy to handle compared with the secondary.

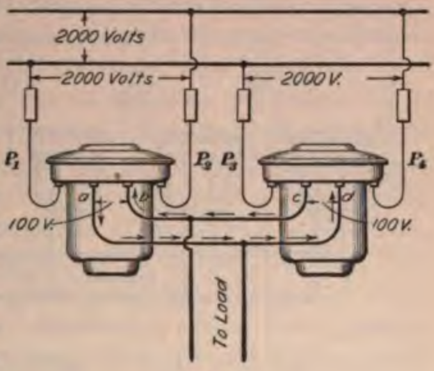

FIG. 23.

**75.** Generally speaking, it is not advisable to operate several transformers in parallel, or *banked*, as it is sometimes termed. This is especially true if the transformers are small and scattered, as on many lighting systems, although it was commonly done some years ago, when transformers were not made in large sizes and where it was necessary to have a large transformer capacity. Suppose a number of transformers are operating in parallel, as shown in Fig. 24. If they do not all have the same voltage regulation, the load may divide unequally between them and one or more of them take more than its share. The result is that the fuses of the heavily loaded transformer blow, and this throws a heavier load on the remaining transformers. Cases have been known where the fuses would blow one after the other after they were once started by one transformer taking more than its share of the load. Of course, if the transformers are all of the same size and of similar design, such trouble is not very likely to happen; but it is better, if possible, to have each transformer supply its own particular part of the load, and if more capacity is needed, to use one large transformer rather than a number of small ones.

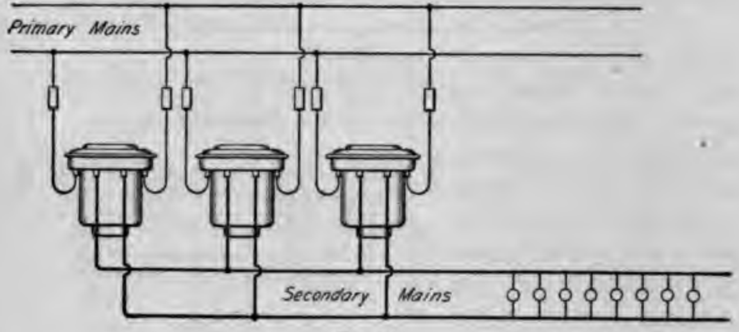

FIG. 24.

**76.** Transformers are very often wound with their primaries and secondaries in two sections, so that they may be connected in series for high voltage and in parallel for low voltage. For example, in Fig. 25 the transformer is wound

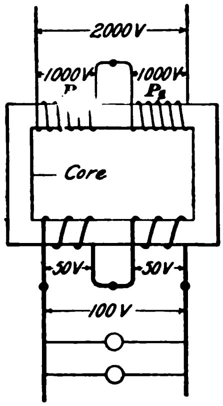

FIG. 25.

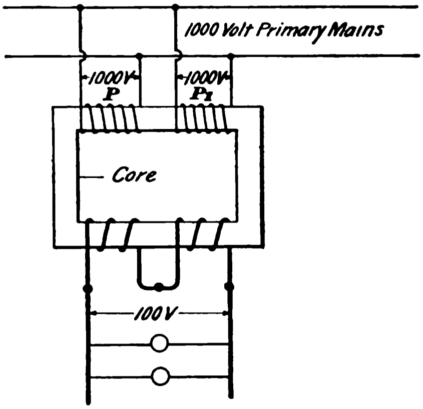

FIG. 26.

with two primary coils $P$, $P_1$, each designed for 1,000 volts and two secondary coils each wound for 50 volts. By connecting the coils $P$, $P_1$ in series, the transformer may be operated on 2,000-volt mains, and if the secondaries are also connected in series, it will supply current to 100-volt secondary mains. If the two primaries $P$, $P_1$ are connected in multiple, as shown in Fig. 26, they may be operated on 1,000-volt mains, and if the secondaries are connected in series, they will supply current at 100 volts. If desired, the secondaries could be connected in parallel to supply current at 50 volts, but the 50-volt secondary circuit is rapidly going out of use. A pressure of 50 volts was, at one time, used quite largely for incandescent lamps operated from transformers, but has given place to 100 to 110 volts, because the latter requires less copper and it is now possible to obtain 100- to 110-volt lamps that operate fully as satisfactory as those made for 50 volts. For operating motors, secondary pressures of 110, 220, or 500 volts are commonly used.

**77.** In many places, plants that were originally installed to operate at 1,000 volts primary pressure have been changed over to 2,000 volts, in order to allow a larger load to be carried without increasing the size of the line wires. In such cases it has been common practice to connect old 1,000-volt transformers up in pairs, as shown in Fig. 27. In this case, the primaries of the two transformers $A$, $B$ are connected in series across the 2,000 volt mains and the secondaries are connected in parallel.

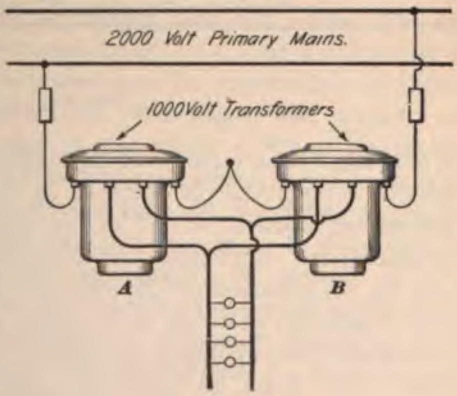

FIG. 27.

**sformers on the Three-Wire System.**—The general [illegible] ncy is to use a few large transformers for supplying [illegible] given district rather than a number of small ones. S [illegible] l transformers are wasteful of power, and ough [illegible] in itself may not represent a very large amount waste, yet when a large number are connected up, the otal amount of energy that might be saved during a year y using a few large transformers may be surprisingly large. Of course, in most cases where the customers are scattered, is impossible to avoid using a number of small trans- rmers, but in business districts it is generally easy to use

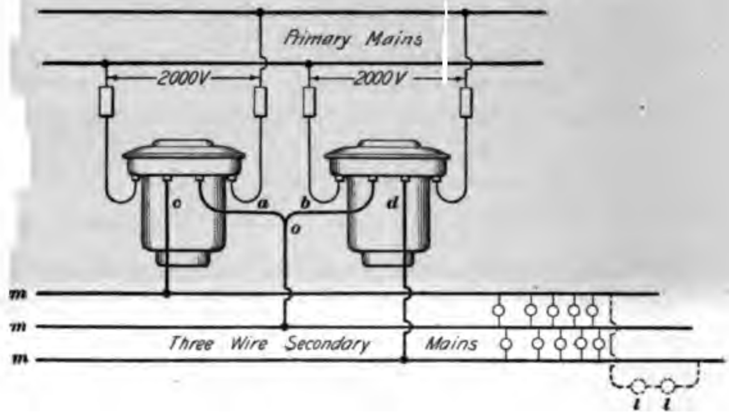

FIG. 28.

a few large transformers of high efficiency. These are frequently connected in pairs so as to feed into three-wire **secondary mains** *m*, *m*, *m*, as shown in Fig. 28. The primaries are connected directly across the line in parallel, and the secondaries are connected in series with the neutral wire connected between them at the point *o*, just as in the case where two dynamos are operated on the three-wire system. Care must be taken in connecting the secondaries to see that the terminals *a* and *b* are of opposite sign. If they are correctly connected, a pair of lamps *l*, *l* connected in series across the outside lines should burn up to full brightness. If they are wrongly connected, the lamps will not light at all, showing that terminals *a* and *b* are of the same polarity and that *c* and *d* are also the same, the secondaries being connected so that the two outside mains are of the same polarity with a common return wire in the middle. If such is found to be the case, the trouble can be remedied by reversing either one of the primary or secondary connections. It may be well to mention in passing that if two transformers are of the same style and make, the terminals of corresponding polarity will usually be brought out of the case in the same way. For example, in Fig. 22, terminals *a* and *c* would be of the same polarity at the same instant. It is always best, however, to test out the connections before connecting things up permanently, and this is especially necessary in case two transformers of different make or type are being dealt with.

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### TRANSFORMERS ON TWO-PHASE CIRCUITS.

**79.** As already mentioned, most two-phase circuits are operated with four wires, and such a system is practically equivalent to two single-phase circuits. The general method of connecting transformers on a four-wire circuit is shown in Fig. 17. If a motor is to be operated, it is necessary to use a transformer on each phase, the capacity of each being one-half that of the motor. When lights are operated, they are connected to each phase in the same way as to a single-phase circuit and the load divided up as evenly as possible between the two phases. If it is necessary to connect two transformers in parallel, as shown at (*a*), Fig. 29, their primaries must both be connected to the same phase. If they were connected to different phases, as indicated by the dotted lines running to Phase *1*, a local current would flow around through the secondary coils, because the two secondary currents would not be in phase and there would be intervals of time when the E. M. F. of one would be greater than that of the other. The secondaries may,

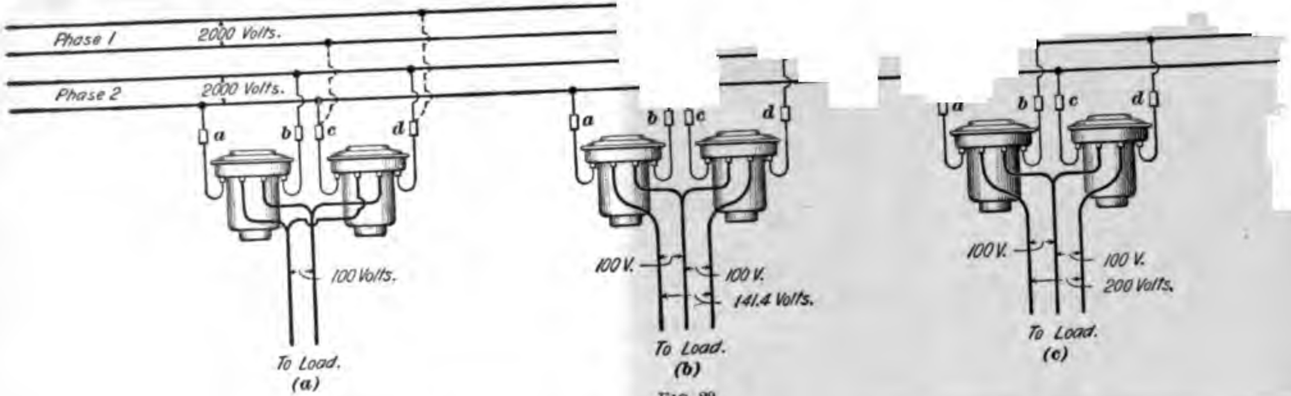
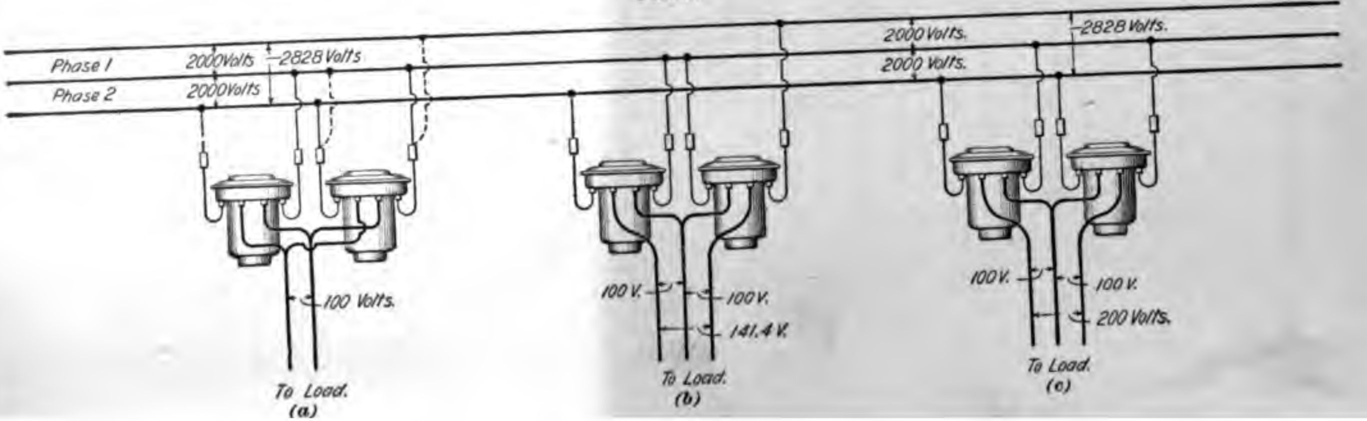
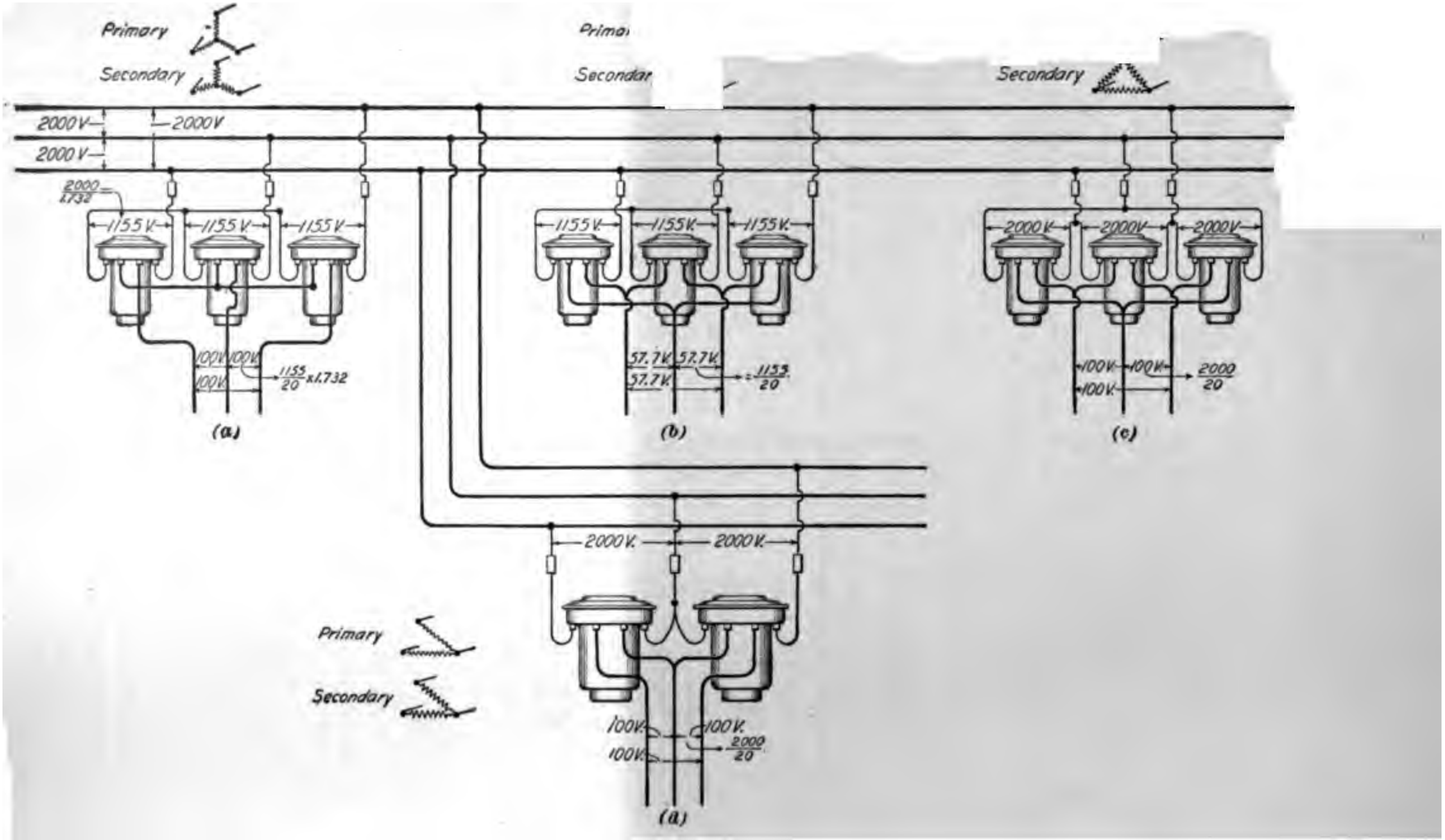

Phase 1
2000 Volts.
Phase 2
2000 Volts.
a
b
c
d
100 Volts.
To Load.
(a)
a
b
c
d
100 V.
100 V.
141.4 Volts.
To Load.
(b)
a
b
c
d
100 V.
100 V.
200 Volts.
To Load.
(c)

FIG. 29.


Phase 1
Phase 2
2000 Volts
2000 Volts
2828 Volts
100 Volts.
To Load.
(a)
100 V.
100 V.
141.4 V.
To Load.
(b)
2000 Volts.
2000 Volts.
2828 Volts.
100 V.
100 V.
200 Volts.
To Load.
(c)

however, be connected in series as shown at (*b*), when the primaries are connected to different phases, forming a kind of three-wire system. The voltage obtained between the outside wires will not be twice that of one transformer, as in the regular three-wire system. If the voltage of each secondary is $E$, the voltage between the two outside wires will be $E \times 1.414$. For example, if each secondary gave 100 volts, the pressure between the outside wires would be 141.4 volts. This is because the E. M. F.'s in the two coils are not in phase. This method of connecting up transformers is, however, not to be recommended, as the voltages on the two sides of the three-wire system are apt to become unbalanced. If a three-wire system is desired, it is best to use the connections shown at (*c*), where both primaries are connected to the same phase. The E. M. F.'s in the two secondary coils are in this case in phase with each other and the pressure across the outside wires is twice that of one secondary coil.

**80.** In connecting transformers to a two-phase system, the aim should be to get the load on the two phases as nearly balanced as possible. Of course, where motors are operated, both phases are used, and, hence, there is not much danger of an unequal division of load. When lamps are connected, one transformer or set of transformers at one point on the circuit can usually be balanced against another group at some other point, so that the load on the whole will be equally divided, as indicated in Fig. 17. Fig. 30 shows a number of different methods of connecting transformers on a two-phase system, using three line wires. In this case, the central wire acts as a common return, and the voltage between the outside wires is 1.414 times that of each phase. The same remarks apply here as in the previous case, and the three-wire arrangement shown at (*b*) is not as generally satisfactory as that shown at (*c*). In both cases the primary pressure is shown as 2,000 volts, and transformers with a ratio of 20 to 1 are taken for the sake of illustration.


Primary
Secondary
2000 V
2000 V
2000 V
2000/1.732
1155 V
1155 V
1155 V
100V
100V
100V
1155/20 x1.732
(a)
Primai
Secondar
1155 V
1155 V
1155 V
57.7V
57.7V
57.7V
= 1155/20
(b)
Secondary
2000 V
2000 V
2000 V
100V
100V
100V
2000/20
(c)
2000 V.
2000 V.
Primary
Secondary
100V.
100V.
100V.
2000/20
(d)

### TRANSFORMERS ON THREE-PHASE CIRCUITS.

**81.** It is customary in America to use three single-phase transformers for transforming from one pressure to another on three-phase circuits. In Europe, three-phase transformers are used in which there are three primary coils and three secondary coils wound on a three-legged iron core. In America, the general practice is to use three standard single-phase transformers connected up either **Y** or Δ, as the case may be. With the Δ arrangement, the power supply will not be entirely crippled even if one of the transformers should become damaged. In some cases the primaries are connected across the lines according to the **Y** scheme, as shown at (*a*), Fig. 31. By using the **Y** connection, there are two primary coils in series between any pair of mains, and, consequently, the pressure on any one primary coil is less than that between the mains; the pressure on each primary is equal to the pressure between the mains divided by 1.732. When the primaries are connected **Y**, the secondaries are usually connected **Y** also, as shown at (*a*). Sometimes, however, the primaries are connected **Y** and the secondaries Δ, as shown at (*b*). If transformers having a ratio of 20 to 1 were connected in this way, the secondary pressure would not be the primary pressure divided by 20, i. e., 100 volts; but would be $\frac{100}{1.732}$, or 57.7 volts. In order to get 100 volts secondary with this scheme of connections, the transformers would have to be wound with a ratio of $\frac{20}{1.732}$ to 1, i. e., 11.55 to 1, approximately. Fig. 31 (*c*) shows transformers with both primaries and secondaries having Δ connections. The arrangements shown at (*a*) and (*c*) are the ones commonly used in connection with three-phase work, as the other scheme either calls for special windings on the transformers or else gives rise to odd secondary voltages. If the primaries are to be connected Δ, then each primary coil must be wound for the full-line voltage. If the primaries are connected **Y**, each primary coil is wound for the pressure divided by 1.732. It is possible to use only two transformers on a three- system, as shown in Fig. 31 (*d*), but this arrangemen s not on the whole as desirable as the others using three ansformers, because if one breaks down the rvice is crippled. This connection is equivalent to the lta arrangement with one side left out. The connections wn in (*c*) are doubtless used more largely than any of the ers. These connections allow the use of transformers nd for standard voltages and a breakdown of one trans- ner does not necessarily interrupt the service.

. **Phase-Changing Transformers.**—Two-phase cur- nts may be transformed to three-phase, and *vice versa*, by means of an arrangement of transformers devised by Mr. C. F. Scott. Fig. 32 shows the connections necessary. Two transformers *A* and *B* have their primary coils *P* and *P'* connected to the two-phase mains as shown. The secondary *S* of transformer *A* has .87 times as many turns as the secondary *S'* of transformer *B*. One end of *S* is connected to the middle point *c* of *S'*. The three-phase lines are attached to terminals *c*, *b*, *d*. This scheme of transformation is used quite largely at Niagara, where two-phase generators are used and the current transformed to three-phase for transmission to Buffalo.

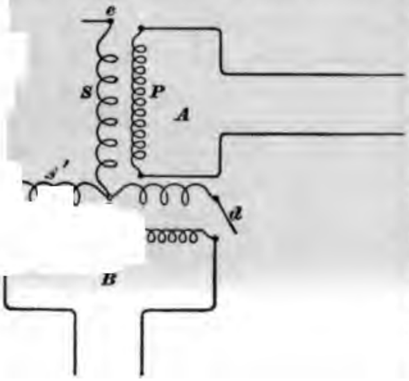


FIG. 32.

**83. Capacity of Transformers on Two- and Three-Phase Systems.**—When transformers are connected on a two-phase system, as, for example, to feed a two-phase motor, each transformer has to be of capacity sufficient to carry half the load. If the three-phase system using three transformers is used, each transformer must be capable of carrying one-third the load. When the transformers are used to operate induction motors, a safe plan to follow is to install 1 kilowatt of transformer capacity for every horsepower delivered by the motor. Thus a 20-horsepower, two-phase induction motor would require two 10-kilowatt transformers; a 30-horsepower three-phase motor would require three 10-kilowatt transformers; and so on. The following table, issued by the General Electric Company, shows the size and number of transformers suitable for 60-cycle, three-phase induction motors.

### TABLE VIII.

#### CAPACITY OF TRANSFORMERS FOR THREE-PHASE INDUCTION MOTORS.

| H. P. of Motor. | Capacity of Transformers. Kilowatts. | |
|---|---|---|
| | Two Transformers. | Three Transformers. |
| 1 | 0.6 | 0.6 |
| 2 | 1.5 | 1.0 |
| 3 | 2.0 | 1.5 |
| 5 | 3.0 | 2.0 |
| 7½ | 4.0 | 3.0 |
| 10 | 5.0 | 4.0 |
| 15 | 7.5 | 5.0 |
| 20 | 10.0 | 7.5 |
| 30 | 15.0 | 10.0 |
| 50 | 25.0 | 15.0 |
| 75 | .... | 25.0 |

## LINE CALCULATIONS FOR ALTERNATING CURRENT.

**84.** The factors that determine the size of line wire for a direct-current transmission apply also, in a general way, to alternating-current systems. The resistance of the line causes a drop in pressure between the station and the distant end, and the line must be proportioned so that this

p will not be excessive. If the load to be carried is
ractically all lights, and if the distances are not long, the
me rules that have already been given for direct-current
ircuits may be applied with sufficient accuracy to alterna-
g-current lines. If, however, the lines are long, say more
n 2 or 3 miles, there are other effects that must be taken
account. It must be remembered that the current is
tinually changing, and this introduces effects not met
h in continuous-current circuits where the current flows
adily in one direction. The size of wire required will
end not only on the amount of the load, but also on the
of load, i. e., on whether it consists wholly of motors or
nts, or a combination of the two. In direct-current cir-
its, it makes no difference, so far as the drop in the line is
cerned, how far the wires are strung apart on the poles,
in an alternating-current circuit this may have an
preciable effect.

**5. Self-Induction of Line.**—Suppose *A*, *B*, Fig. 33,
esent two line wires, and suppose, for the present, that a continuous current is flowing in them. The result of this current will be to set up a magnetic field around each wire as indicated by the dotted circles, and as the current is supposed to be steady, these lines of force will not change in any way and will have no effect on the current. Suppose, however, that the current is alternating instead of continuous. The lines of force surrounding the wires will then change with the change in current; as the current increases, the magnetic field will be built up and lines of force will expand, and as it decreases, the lines will collapse on the wire. The result is that there is a cutting of lines of force by the line wires; or, a still better way of looking at it is that the number of lines threading the space between the wires is constantly changing, and the result of this changing magnetic field is that an electromotive force is set up in the

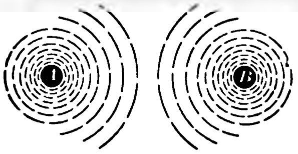


FIG. 33.

wires. This E. M. F. of self-induction, as it is called, depends on the number of lines of force that are set up between the wires and on the rate at which these lines change; in other words, it depends on the frequency of the current. The effect of this E. M. F. of self-induction is to make the circuit have apparently a greater resistance than it has when direct current is used, because a certain portion of the pressure applied to the circuit is used up in overcoming this E. M. F. of self-induction. By referring to Fig. 33, it will be seen that the farther the line wires are apart, the more room there will be between them for lines to be set up, and, hence, the greater will be the E. M. F. of self-induction. If the wires could be placed side by side in contact with each other, there would be little or no self-induction. This, however, is not possible, and lines, as strung on poles, always possess a certain amount of self-induction. When the two wires are twisted together to form a cable, as in underground work, they have little or no self-induction. The amount of the E. M. F. set up in a conductor depends on the rate at which lines of force are cut. If the alternating current flowing through a line changes very rapidly, it is evident that the E. M. F. of self-induction will be much higher than if it changed slowly, because the cutting of lines of force would not be so great in the latter case.

**86.** This E. M. F. of self-induction, as stated above, is, to a certain extent, opposed to the current and increases the apparent resistance of the circuit. Its effect is to make the current lag behind the E. M. F., so that the current and E. M. F. do not come to their maximum values at the same instant. This self-induction may also be present to a greater or less degree in the devices that are operated on the circuit. A load of lamps possesses very little self-induction, but a load of induction motors may introduce quite a large amount, and thus make the current lag considerably behind the E. M. F.

**87.** If we have direct current or if there is no self-induction in the alternating-current circuit, the power factor is 1, and the watts are given directly by the product of the current and E. M. F. If in an alternating system we have to deliver $W$ watts, the apparent watts, or **volt-**

**ıperes,** as they are sometimes called, will be $\frac{W}{f}$, where

the power factor, and the current will be

$$C = \frac{W}{E \times f}. \qquad (13.)$$

**8.** The greatest value that the power factor can have

and it has this value very nearly when the load consists

ly of incandescent lamps or any other load that has no

reciable self-induction. Even when the load is all lights,

transformers have a slight amount of self-induction, so

t the power factor may be about .98. Where the load is

motors, the power factor may be taken as .80, and where

load is a combination of motors and lights, as about .85.

XAMPLE.— 10 kilowatts are to be delivered at the end of a trans-

ssion line to a load that consists wholly of motors. (*a*) What will be

apparent number of watts delivered, i. e., what will be the product of the current and voltage at the end of the line? (*b*) What will be the current if the pressure at the end of the line is 1,000 volts?

SOLUTION.—Since the load is all motors, we may take the power factor as .80; hence, we have

(*a*) $\text{Apparent watts} = \frac{10{,}000}{.80} = 12{,}500.$ Ans.

(*b*) The current will be $\frac{12{,}500}{1{,}000} = 12.5$ amperes. Ans.

NOTE.—If the power factor had been 1 instead of .80, the apparent watts would have been the same as the true watts and the current would be 10 amperes.

**89.** From what has just been said, it will be seen that the effect of an inductive load, and, consequently, low power factor, is to necessitate a larger current for a given amount of power transmitted than would be required if the load were non-inductive. This means, then, that a larger line wire must be provided if the drop is to be kept the same.

## FORMULAS FOR LINE CALCULATIONS.

**90. Estimation of Cross-Section of Lines.**—It has been shown that in a direct-current transmission line a certain drop in voltage is equivalent to a corresponding loss in power. For example, if the drop were 10 per cent. of the delivered voltage, the loss of power in the line would also be 10 per cent. of that delivered at the receiving end. With alternating current, the percentage of drop in pressure may be quite different from the percentage loss in power. In case alternating current were used in the circuit mentioned above, the drop in voltage would very likely be more than 10 per cent., on account of the self-induction of the line. Just what the drop would be, corresponding to a given loss in power, depends on the size of the wire, distance apart on the poles, etc. The exact calculation of line wires for alternating current is a complicated matter, but in nearly all the cases that arise in practice they can be estimated with sufficient accuracy by means of comparatively simple formulas. It is seldom that a wire can be obtained of exactly the same size calculated unless it is made to order, so that the approximate formulas give sufficiently close results for practical work. The following formulas, originated by Mr. E. J. Berg, will be found convenient for estimating alternating-current lines. We will denote the different quantities entering into the calculations as follows:

$D$ = distance in feet over which power is transmitted (this distance is to be taken one way only, i. e., it is the single distance);

$W$ = total watts delivered at the end of the line (this number must express the actual watts delivered, not the apparent watts);

$P$ = percentage of *power* lost in line (it should be noted that this percentage is that of the power *delivered*, not the power *generated;* also, it is the percentage *power* lost, not the *percentage drop in voltage*);

$E_2$ = voltage required at the receiving end of the line, i. e., the voltage at the end where the power is delivered;

$t$ = a constant having the following values:

2,400 for a single-phase system operating lights only.
3,000 for a single-phase system operating motors and lights.
3,380 for a single-phase system operating motors only.
1,200 for a three-wire three-phase, and four-wire two-phase system, all lights.
1,500 for a three-wire three-phase and four-wire two-phase system, motors and lights.
1,690 for a three-wire three-phase and four-wire two-phase system, all motors.

The cross-section of the wire required for any given case may then be calculated from the following formula:

$$\text{Circular mils} = \frac{D \times W}{P \times E_2^2} \times t. \qquad \textbf{(14.)}$$

EXAMPLE.— 300 horsepower is to be transmitted by means of the three-phase system over a distance of 5 miles with a loss of 10 per cent. of the power delivered. The pressure at the end of the line is to be 4,000 volts and the power is to be used altogether for operating motors. Calculate the size of line wire required.

SOLUTION.—In this case the distance $D$ is $5,280 \times 5 = 26,400$ feet. The watts delivered will be $300 \times 746 = 223,800$. $P = 10$ and $E_2 = 4,000$. The constant $t$ for this case will be 1,690; hence, we have from formula

$$\text{Circular mils} = \frac{26,400 \times 223,800}{10 \times 4,000 \times 4,000} \times 1,690 = 62,407,$$

or about a No. 2 B. & S. Ans.

**91. Estimation of Current in Lines.**—The current in the line wires of an ordinary continuous-current line is easily obtained by dividing the watts supplied by the voltage at the end of the line. We can obtain the current in the case of alternating-current systems by using a similar formula and multiplying by a constant, to allow for the circumstances under which the current is used. We may then use the following formula:

$$\text{Current in line} = \frac{W}{E_2} \times T, \qquad \textbf{(15.)}$$

where $W$ = watts delivered;
$E_2$ = voltage at the receiving end of the line;
$T$ = constant referred to above.

VALUES OF CONSTANT $T$.

| | |
|---|---|
| Single-phase system, all lights | 1.052. |
| Single-phase system, motors and lights | 1.176. |
| Single-phase system, all motors | 1.250. |
| Two-phase, four-wire system, all lights | .526. |
| Two-phase, four-wire system, motors and lights. | .588. |
| Two-phase, four-wire system, all motors | .625. |
| Three-phase system, all lights | .607. |
| Three-phase system, motors and lights | .679. |
| Three-phase system, all motors | .725. |

EXAMPLE 1.— 100 kilowatts are delivered by means of the two-phase, four-wire system to a mixed load of motors and lights. The pressure at the receiving end of the line is 2,000 volts. Calculate the current in each line wire.

SOLUTION.— 100 kilowatts = 100,000 watts. For this case the constant $T$ will be .588; hence,

$$\text{Current} = \frac{100000}{2000} \times .588 = 29.4 \text{ amperes. Ans.}$$

EXAMPLE 2.— 200 kilowatts are transmitted by means of the three-phase system, the voltage between lines at the receiving end being 4,000 volts. The load consists wholly of motors; calculate the current in each line.

SOLUTION.— 200 kilowatts = 200,000 watts. For this case the value of $T$ will be .725; hence,

$$\text{Current} = \frac{200000}{4000} \times .725 = 36.25 \text{ amperes. Ans.}$$

**92. Estimation of Drop.**—The volts drop in the line for a continuous-current system would be $\frac{P \times E_2}{100}$, when $P$ is the percentage of delivered power lost and $E_2$ is the voltage at the receiving end of the line. This formula can be made to give the approximate drop in an alternating-current line by multiplying it by a constant that takes into account the conditions under which the line is operated. We may then write

$$\text{Volts drop in line} = \frac{P \times E_2}{100} \times M. \qquad \textbf{(16.)}$$

The value of the constant $M$ depends on the frequency, the power factor of the load, and the size of the line wire. The value of $M$, under various conditions, is given in the following table:

## TABLE IX.

| No. of B. & S. Gauge. | Area. Circular Mils. | Values of *M*. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 30 Cycles. | | | 60 Cycles. | | | 125 Cycles. | | |
| | | Lights Only. | Motors and Lights. | Motors Only. | Lights Only. | Motors and Lights. | Motors Only. | Lights Only. | Motors and Lights. | Motors Only. |
| [illegible] | [illegible] | [illegible] | [illegible] | 1.24 | 1.64 | 1.85 | 1.85 | 2.44 | 3.06 | 3.14 |
| [illegible] | [illegible] | [illegible] | [illegible] | 1.14 | 1.49 | 1.63 | 1.62 | 2.15 | 2.62 | 2.67 |
| [illegible] | [illegible] | 1 | 1. | 1.05 | 1.39 | 1.46 | 1.42 | 1.92 | 2.25 | 2.29 |
| [illegible] | [illegible] | [illegible] | [illegible] | .00 | 1.30 | 1.32 | 1.28 | 1.73 | 1.96 | 1.99 |
| [illegible] | [illegible] | 5 | [illegible] | .00 | 1.23 | 1.21 | 1.16 | 1.57 | 1.74 | 1.73 |
| [illegible] | 00 | 8 | 1.00 | 1.00 | 1.16 | 1.11 | 1.06 | 1.44 | 1.54 | 1.53 |
| [illegible] | 4 | [illegible] | .00 | 1.00 | 1.11 | 1.04 | 1.00 | 1.35 | 1.38 | 1.38 |
| [illegible] | 2 | [illegible] | .00 | 1.00 | 1.07 | 1.00 | 1.00 | 1.26 | 1.26 | 1.22 |
| [illegible] | [illegible] | 1 | 1.00 | 1.00 | 1.04 | 1.00 | 1.00 | 1.19 | 1.16 | 1.11 |
| [illegible] | [illegible] | [illegible] | 1.00 | 1.00 | 1.02 | 1.00 | 1.00 | 1.14 | 1.08 | 1.03 |
| 7 | [illegible] | [illegible] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.09 | 1.01 | 1.00 |
| 8 | 16,509 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.06 | 1.00 | 1.00 |

**Example.**— 600 kilowatts are to be transmitted a distance of 6 miles by means of the three-phase 60-cycle system. The loss in the line is to be limited to 10 per cent. of the power delivered, and the pressure at the receiving end of the line is to be 6,000 volts. The current is to be supplied to a mixed load of motors and lights. Calculate (*a*) the size of the line wire; (*b*) the current in each line; (*c*) the volts drop in the line; and (*d*) the pressure generated by the dynamos at full load.

**Solution.**— 600 kilowatts = 600,000 watts. 6 miles = 6 × 5,280 = 31,680 feet. Using formula **14,** we have, since *t* for this case is 1,500,

$$\text{Circular mils} = \frac{31,680 \times 600,000 \times 1,500}{10 \times 6,000 \times 6,000} = 79,200.$$

(*a*) A No. 1 B. & S. wire would therefore be used. Ans.

In order to obtain the current in each line we use formula **15,** and for this case the value of $T$ will be .679; hence,

(*b*) $\text{Current} = \frac{600000}{6000} \times .679 = 67.9$ amperes. Ans.

(*c*) In order to calculate the volts drop in the line, we use formula **16.** For a No. 1 wire and a frequency of 60 cycles on a combined lamp and motor load, the value of the constant $M$ is found to be 1.21 by referring to the table; hence,

$$\text{Volts drop} = \frac{10 \times 6{,}000}{100} \times 1.21 = 726. \quad \text{Ans.}$$

($d$) Since the drop in the line is 726 volts, the pressure at the dynamo must be $6{,}000 + 726 = 6{,}726$ volts when the full-load current is being delivered. Ans.

NOTE.—In the above example, the drop in the line would have been only 600 volts if continuous current were used.

### EXAMPLES FOR PRACTICE.

1. 250 horsepower is to be supplied to 60-cycle induction motors by means of the two-phase, four-wire system over a line 3 miles long. The pressure at the distant end of the line is to be 4,000 volts and the loss in the line is to be limited to 8 per cent. of the power delivered. Calculate ($a$) the size of the wire required; ($b$) the current in each line wire; ($c$) the drop in the line.

Ans. ($a$) 39,000 cir. mils, nearly; about No. 4 B. & S.
($b$) 29.14 amperes.
($c$) 320 volts.

2. A three-phase alternator delivers 400 horsepower to a mixed load of motors and lights. The pressure at the distant end of the line is 3,000 volts. Calculate the current in each line. Ans. 67.54 amperes.

3. 5,000 incandescent lamps are supplied with current from a single-phase alternator, having a frequency of 125, over a distance of 3 miles. The loss in the line is to be limited to 10 per cent. of the power delivered and the pressure at the end of the line is to be 3,000 volts. Allow 60 watts for each lamp supplied and calculate ($a$) the size of the line wire; ($b$) the current in the line; ($c$) the volts drop in the line; ($d$) the voltage at the generator.

Ans. ($a$) 126,720 cir. mils, or about No. 00 B. & S.
($b$) 105.2 amperes.
($c$) 576 volts.
($d$) 3,576 volts.

## POWER MEASUREMENT.

### DIRECT-CURRENT CIRCUITS.

**93.** It has been shown that the power in watts supplied to any direct-current circuit may be obtained by multiplying the current by the E. M. F. across the lines. For example, in Fig. 34, we may, at any time, obtain the watts supplied to the motor $M$ by multiplying the reading given by the

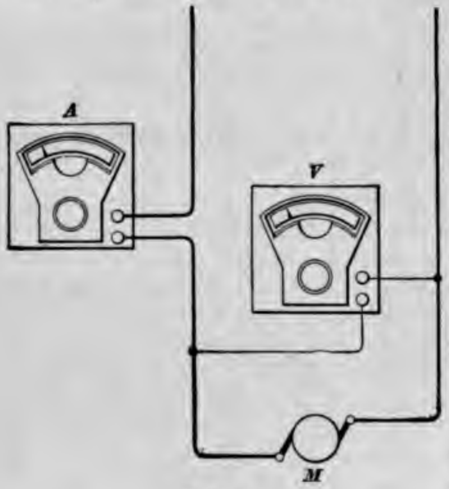


FIG. 34.

ammeter $A$ by that given by the voltmeter $V$. The number of watts so obtained represents the *rate at which work is being done* at the instant the readings are taken. It must be remembered that the watt is a unit of electrical power, not work, and expresses *rate of doing work*. The electrical unit of work is the joule, and when work is done at the rate of *1 joule per second*, 1 watt is expended. By combining the voltmeter and ammeter we can make an instrument the indications of which will be equal to the product of the current and voltage, and thus indicate the watts directly. Such an instrument is called an *indicating wattmeter*. Fig. 35 shows a Weston wattmeter of the kind referred to. The principle on which this wattmeter operates will be understood by referring to Fig. 36. Two stationary coils, consisting of a few turns of heavy wire, as indicated by $a$, $a$, are mounted side by side, and a small coil $b$, consisting of a large number of turns of fine wire, is mounted between them on jeweled bearings. The motion of the swinging coil is controlled by spiral

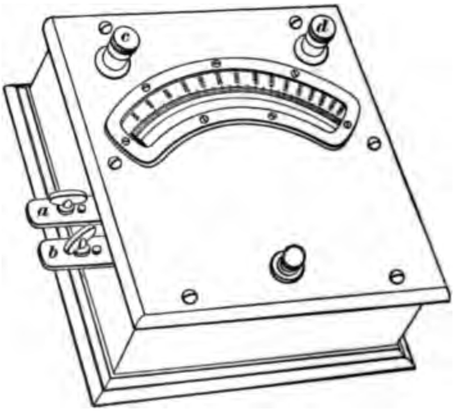


FIG. 35.

springs *c*, *c*, which also serve to carry the current into the coil. The pointer is attached to the axis of the swinging coil and plays over a horizontal scale. The stationary coils *a*, *a* are connected in series in the circuit, so that the current supplied to the motor or other device passes through them. The swinging coil is connected directly across the circuit, and a high resistance *T* is usually connected in series with the swinging coil, so as to limit the current flowing through it to a very small amount; *d*, *d* are the current terminals of the instrument, i. e., the terminals that connect to the fixed coils; and *e*, *e* are the terminals of the swinging coil.

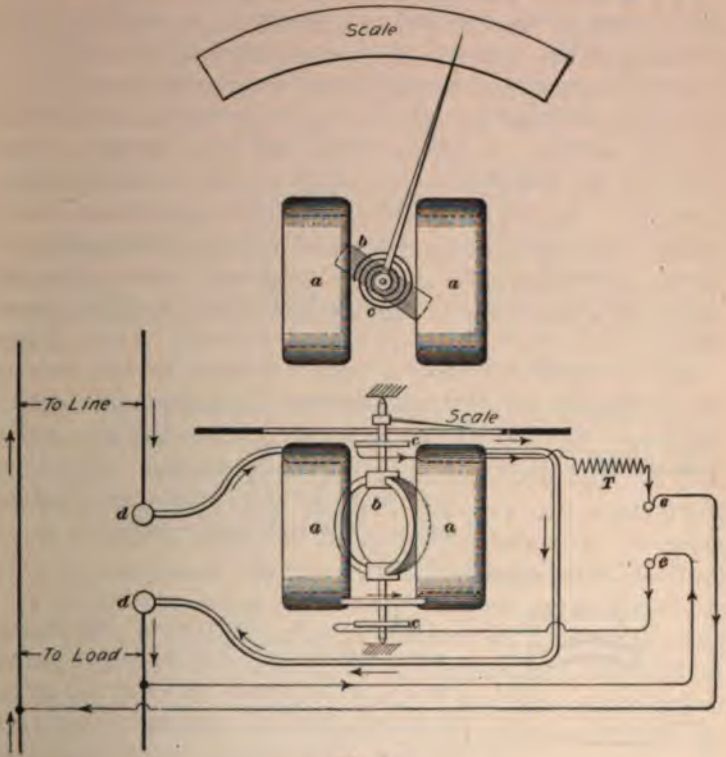


FIG. 36.

**94.** From the way in which the instrument is connected it is seen at once that the current in the fixed coils is the same as the current supplied to the device operated; also, since the swinging coil is connected directly across the circuit, like a voltmeter, the current in the swinging coil will be proportional to the voltage between the lines. Now, the twisting force exerted upon the swinging coil depends on the current in the coil and the strength of the field. The strength of the magnetic field set up through the fixed coil is directly proportional to the current flowing through it, so that the twisting force exerted on the swinging coil depends on the product of the current and the voltage; consequently, the instrument may be graduated to read in watts. Care must be exercised when connecting a wattmeter in a circuit not to get the current and pressure terminals confused, because if the current terminals were connected across the line, a short circuit would result, and the instrument would, in all probability, be destroyed. There is generally no excuse for making such a mistake as this, because the terminals are entirely different in appearance; nevertheless, it has been known to occur. If the fine-wire coil is connected in series in the circuit, no damage will result, but scarcely any current will flow on account of the high resistance so introduced.

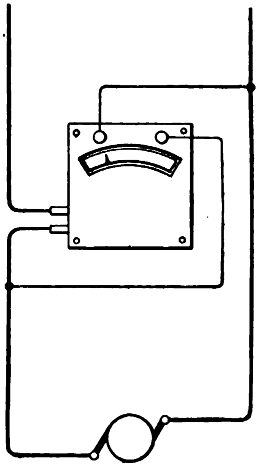


FIG. 37.

**95.** If an indicating wattmeter were connected to a motor as shown in Fig. 37, it would indicate the power supplied, and its readings would vary as the load on the motor changed. Where power is sold to customers from a central station, it is generally more important to know the total amount of work done during a given interval of time than the power that the motor or other device is taking at any particular instant. For example, the company supplying power wishes to know just how much work has been done during, say, 1 month, so that the bill may be rendered accordingly. If we do work at the rate of 1 watt, i. e., 1 joule per second, and keep this up for an hour, we do a certain definite amount of work. This quantity of work is known as the **watt-hour.** 1 joule is equivalent to .7373 foot-pound, and .7373 foot-pound per second is 1 watt. If, then, we work at the rate of 1 watt and keep it up for 1 hour, or $60 \times 60$ seconds, at the end of the hour we will have done $.7373 \times 60 \times 60 = 2{,}654.28$ foot-pounds of work. In order to obtain the total amount of work expended on any device, we must use some instrument that will give us the product of the average rate at which work has been done by the time during which it was done. Such an instrument is known as a **recording wattmeter,** or **watt-hour meter.** The latter name is preferable, because the readings of these instruments do not give watts, but watt-hours.

**96.** Fig. 38 shows a Thomson recording wattmeter, which is without doubt more largely in use than any other one type. It is in principle a wattmeter similar to that shown in Fig. 36, except that the fine-wire coil is arranged so as to revolve instead of being merely deflected. In order to bring this about, the fine-wire coil is made up in the form of a small drum-wound armature without an iron core, as shown at *a*. This armature is mounted on a vertical shaft and is provided with a small silver commutator, the current being led into the armature by means of the silver-tipped brushes *b*. The current coils are shown at *c*, *c*. The meter is, in fact, a small electric motor without iron in either its armature or field. The lower end of the shaft carries a copper disk that revolves between the poles of permanent magnets. The eddy currents set up in the disk retard the motion of the armature, just as the reaction of the current in the armature of an ordinary dynamo retards the engine. This retarding action of the disk can be adjusted by swinging the poles of the magnets in or out from the periphery.

The speed with which the meter runs is thus made proportional to the watts expended at any given instant, and the *total number of revolutions* that the disk makes in a given period is proportional to the total number of watt-hours of work done during that period.

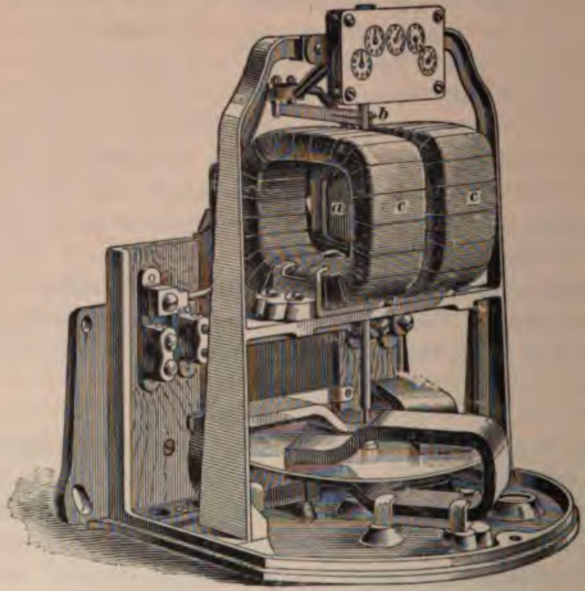


FIG. 38.

The number of watt-hours used during a given time is obtained by taking readings from the dials at the top of the meter in much the same way as a gas meter is read. On some meters, the reading as taken from the dial has to be multiplied by a constant in order to give the watt-hours. This constant is marked on the dial.

**97.** Fig. 39 shows the method of connecting up a Thomson recording wattmeter of small capacity on a two-wire circuit. The wires from the line always enter the meter at the left, and those going to the load pass out at the right. When the meter is of large capacity, only one side of the circuit is run through it and a small "potential wire" is run in from the other side, so as to put the armature across the circuit. This method of connection is shown in Fig. 40. Fig. 41 shows a meter connected to a three-wire circuit.

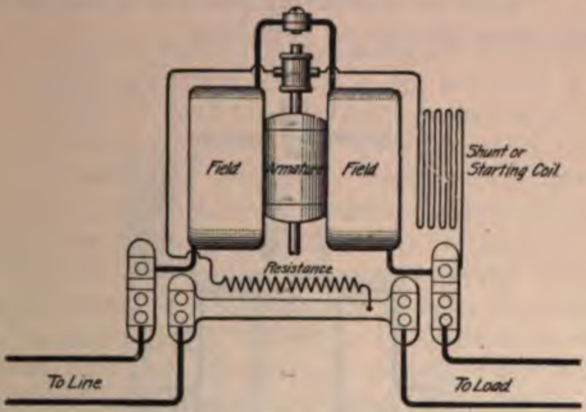


FIG. 39.

The neutral wire does not enter the meter, but a tap is taken off from it so as to put the armature across one side of the circuit. The field coils are connected in series with the outside wires, as shown. In Fig. 39 the starting, or shunt, coil, as it is sometimes called, is a coil of fine wire in series

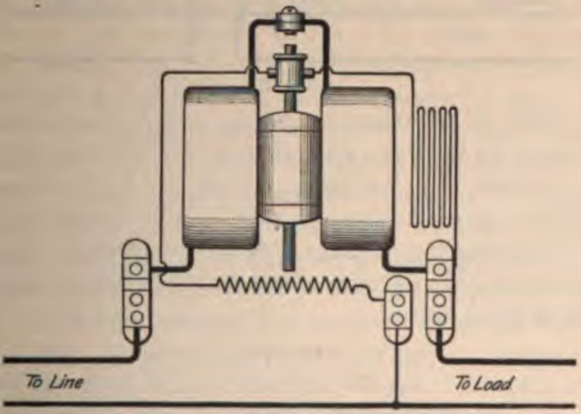


FIG. 40.

with the armature and placed inside one of the field coils. It provides just about enough field to start up the meter, so that when a light load is thrown on, the meter will start up readily. The coil is intended to overcome friction and make the meter more accurate on light loads.

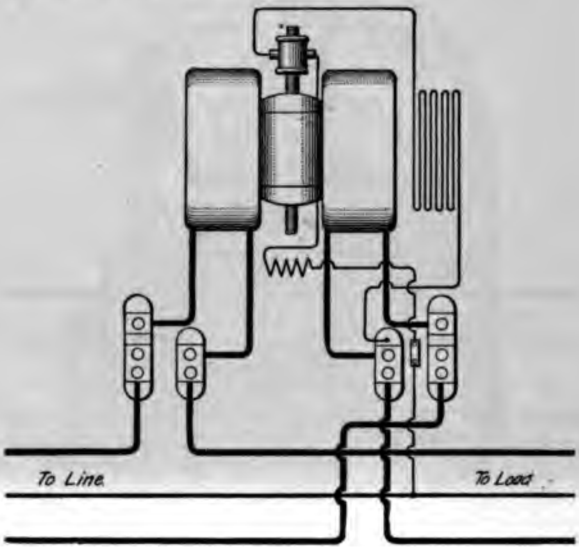


FIG. 41.

**98.** The above remarks relating to recording wattmeters have been made with special reference to the Thomson meter, because this one is so widely used. It is accurate and has the great advantage that it will operate on either direct or alternating current. If properly cared for it will give good results, but the commutator is delicate and must be kept in good order.

## ALTERNATING-CURRENT CIRCUITS.

**99. Single-Phase Circuits.**—The power supplied to an alternating-current circuit cannot generally be obtained by multiplying the current by the voltage. The power factor of the load must be taken into account, and the only case where the volts multiplied by amperes would be equal to the watts would be where the device operated had practically no self-induction or electrostatic capacity, as, for example, a load of lamps.

**100.** The best method of measuring the power supplied to an alternating-current circuit is by means of a wattmeter. There are methods of doing it by means of ammeters and voltmeters, but they are seldom used in practical work. An indicating wattmeter connected as shown in Fig. 37 on a single-phase alternating-current circuit will indicate the actual watts expended. If a record of the watt-hours supplied is desired, a Thomson recording wattmeter may be connected in the same way as for a direct-current circuit, as shown in Fig. 39, 40, or 41, because, as already mentioned, this type of recording wattmeter will work on either direct or alternating current. Also, the Thomson meter may be used on any of the ordinary frequencies and still give accurate results.

**101. Induction Wattmeters.**—There are a number of different types of recording wattmeters that operate on the principle of the induction motor. In these meters two coils are usually provided (for a single-phase meter), one being a current coil and the other a potential coil. These coils are so arranged that the currents in them differ in phase, and the shifting magnetism so set up acts on a small armature, which usually takes the form of a copper or aluminum disk or drum. Currents are set up in this armature under the influence of the changing magnetic field, just as in the squirrel-cage armature of an induction motor; in fact, induction meters are practically small induction motors. Fig. 42 shows an induction meter (single-phase) made by the Fort Wayne Electric Works. *D* is the revolving aluminum armature, which is in the form of an inverted cup; *a* is the current coil, which is wound on an iron core, the pole piece of which faces *D*. The potential coil occupies a similar position back of the armature *D*, and is therefore not seen in the figure. The fine-wire potential coil is used in connection with a choke coil, so that the currents in *a* and the potential coil differ in phase, and the result is that a turning effort is exerted on drum *D*. The cup-shaped drum *D* answers both for the armature and damping disk, and the speed control is effected by the permanent magnet *E*, which exerts a dragging action on the armature. The adjustment of the meter is brought about by raising or lowering *E*, thus making the meter run slower or faster, as desired. Induction meters can, of course, be used on alternating current only and current of the frequency for which they are adjusted. They have one advantage over the Thomson meter in that they have no commutator to give trouble.

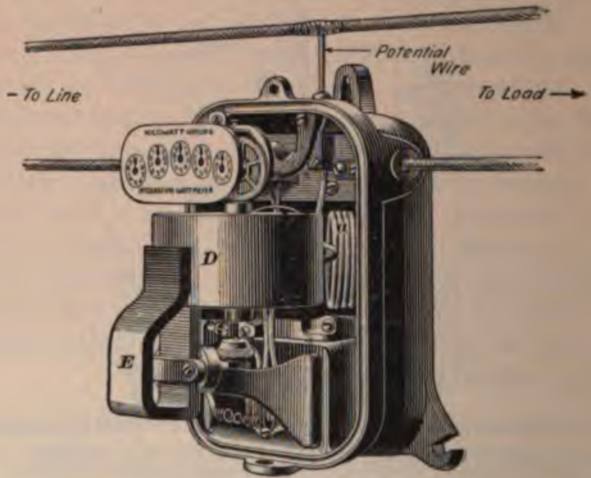


FIG. 42.

**102. Ampere-Hour Meters.**—Many of the meters formerly used recorded ampere-hours instead of watt-hours. It is evident that the number of ampere-hours gives no idea as to the amount of work done during a given time, unless the pressure at which the current was supplied is known. For example, 200 ampere-hours at a pressure of 50 volts would be equal to 10,000 watt-hours, assuming that the pressure remained constant at 50 volts during the time and that the power factor of the load was 1. If the pressure were 100 volts, the same meter reading would be equivalent to 20,000 watt-hours. Ampere-hour meters are not used nearly so much as formerly. Practically, all the modern meters are watt-hour meters, and, hence, take account of variations in pressure as well as of current. The earlier types of Westinghouse, or Shallenberger, and Duncan meters measured in ampere-hours. The great objection, however, to the use of ampere-hour meters on alternating-current circuits is that, if the load is at all inductive, i. e., if the power factor is less than 1, they run up a larger bill against the consumer than they should for the actual power supplied. An ampere-hour meter takes no account of the power factor, but simply measures up the current; consequently, for the same actual power used it will run up a larger bill than a recording wattmeter would if it were connected on the same circuit. The customer pays for power, not for current, and the ampere-hour meter readings multiplied by the average voltage would give a larger number of watt-hours than was actually used. Of course, when the load is all lights, the power factor is practically 1, and for such service the ampere-hour meter gives fair readings; but when it comes to measuring power supplied to induction motors or other inductive loads, recording wattmeters should be used.

**103.** If the power supplied to an alternating-current single-phase circuit is to be measured by means of an ammeter and voltmeter, the power factor $f$ of the circuit must be known. The watts may be obtained by solving formula **13** for $W$, which gives

$$W = C \times E \times f, \qquad (\mathbf{17.})$$

where $C$ is the ammeter reading and $E$ the voltmeter reading. In most cases, the value of the power factor $f$ is not known exactly, so that it is best to use a wattmeter.

**104. Two-Phase Circuits.**—In order to measure the power supplied to any receiving device operated on a two-phase system, as, for example, a two-phase induction motor, it is best to use two wattmeters, one connected in each phase, as shown in Fig. 43. The total power supplied will then be the sum of the readings of the two meters. If the load on the two phases is exactly balanced, one wattmeter may be connected in one phase and its reading multiplied by 2. It is not safe to do this, however, unless it is known that the two sides are balanced. If only one wattmeter is available, it may sometimes be arranged so that it may be connected first in one side and then in the other, but as a rule this is troublesome. On a three-wire two-phase system, the two wattmeters would be connected in very much the same way as shown in Fig. 43, one end of each of the pressure coils being connected to the middle wire. If $f$ is the power factor of a balanced two-phase system, $C$ the current in each phase, and $E$ the E. M. F. per phase; then the watts supplied will be

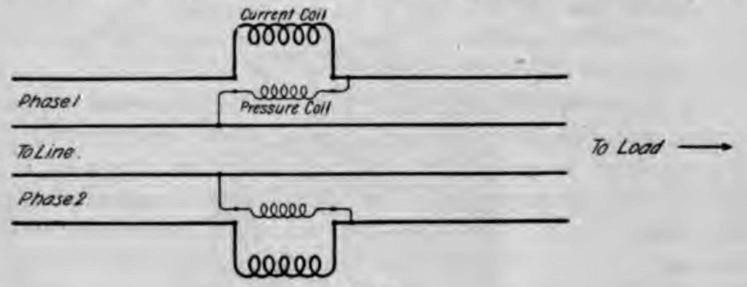


FIG. 43.

$$W = 2\,CEf. \qquad \textbf{(18.)}$$

EXAMPLE.—Power is delivered to a two-phase induction motor having a power factor of .85. The current in each phase is 30 amperes, and the voltage of each phase 220 volts. Calculate the horsepower supplied to the motor.

SOLUTION.—We have

$$\begin{aligned} \text{Watts} &= 2\,C \times E \times f \\ &= 2 \times 30 \times 220 \times .85 \\ &= 11{,}220. \end{aligned}$$

Hence, $\text{H P.} = \frac{11220}{746} = 15$, nearly. Ans.

**105. Three-Phase Circuits.**—In the three-phase system we do not usually have three distinct circuits. If three distinct circuits were used, six wires would be necessary. Each wire serves alternately as the return for the other two, and on this account wattmeters have to be connected somewhat differently than on an ordinary circuit when measurements of power are being made. If the power is supplied to a balanced load, as, for example, a load consisting wholly of three-phase motors, one wattmeter may be used to measure the power, as indicated in Fig. 44. The method of connecting the potential coil $p$ and the resistances $r_1$, $r_2$, and $r_3$ should be noted. These resistances are connected as shown in order to obtain an artificial neutral point, similar to the common connection of a **Y**-connected three-phase armature. This combination of resistances is sometimes called a "**Y** resistance," or a "**Y** box." Although the current coil is in one side of the system only, the instrument can be calibrated to read the total watts delivered, assuming, of course, that the load is balanced.

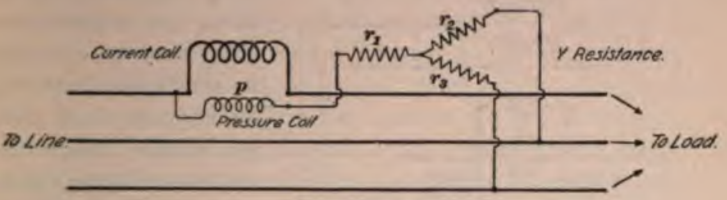


FIG. 44.

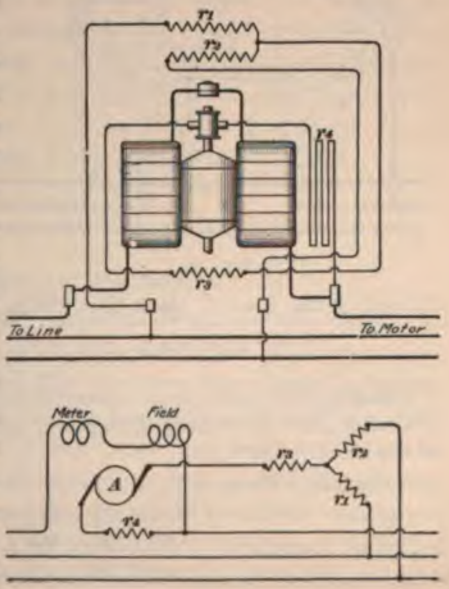


FIG. 45.

**106.** Fig. 45 shows how to connect a Thomson recording wattmeter with its **Y** resistance so as to measure the power on a balanced three-phase circuit. The recording meters are so calibrated that their reading multiplied by the meter constant, if there is one, gives the total power supplied. Fig. 45 shows the connections when the meter is used on circuits where the pressure is not over 500 volts. When the pressure is higher than this, small transformers *t*, *t*, Fig. 46, are used to step down the voltage for the pressure coil of the recording wattmeter, and the connections are as shown in the figure referred to.

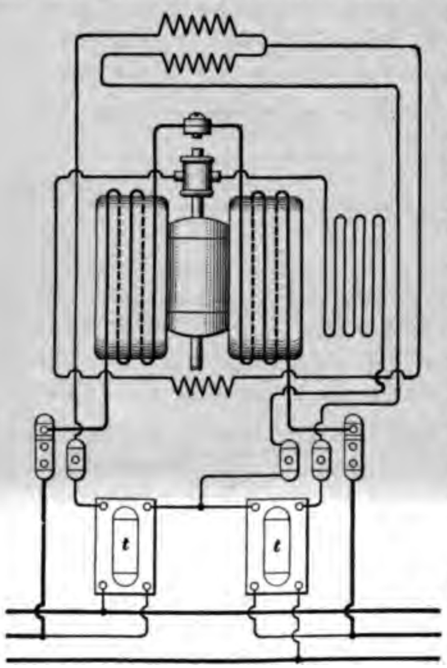


Fig. 46.

**107.** If the current in each line of a balanced three-phase system is $C$, the pressure between the lines $E$, and the power factor of the load $f$, then the watts delivered will be

$$W = 1.732 \times E \times C \times f. \qquad \textbf{(19.)}$$

Example.—A three-phase motor takes a current of 40 amperes from a 500-volt line. How many horsepower are supplied if the power factor of the motor is .80 ?

Solution.—We have

$$\begin{aligned} W &= 1.732 \times E \times C \times f \\ &= 1.732 \times 500 \times 40 \times .80 \\ &= 27{,}712. \end{aligned}$$

Hence, $\text{H. P.} = \frac{27712}{746} = 37.1.$ Ans.

**108.** The power factor of induction motors varies greatly with the load and also with the size of the motor. The power factor of a good motor of fair size running at full load will usually lie between .85 and .90. When running at $\frac{1}{2}$ to $\frac{3}{4}$ load, the power factor may drop to .75 or .80. For this reason, the student is cautioned against making power calculations in connection with induction motors or any other piece of alternating-current apparatus by multiplying the current and E. M. F. together. Such calculations may be far from correct, unless the power factor is known and taken into account as shown above. Take, for example, the common case where a transformer primary is connected, say, to 2,000-volt mains and its secondary is open and supplying no current whatever. A small current will flow through the primary; in this case we will say .25 ampere. The apparent power that the primary is taking is $.25 \times 2{,}000 = 500$ watts. If the power were measured by means of a wattmeter, it would be found that the actual power supplied was not nearly as large as this; it might not, in fact, be more than one-half this amount. On the other hand, if the transformer were working on a full load composed of lights, the product of the current and the E. M. F. would give very nearly the actual power, because the power factor would, under such circumstances, be nearly equal to 1.

## SPECIAL METERS.

**109. The Two-Rate Meter.**—Most electric-light stations have their period of heaviest load for a few hours only, in the evening. During the daytime the plant is lightly loaded and a large part of the machinery is standing idle. In order to obtain a "day load" and thus work the plant to best advantage, some companies supply power during the daytime at specially low rates in order to induce customers to use electric motors. For measuring the power supplied to such customers, **two-rate meters** are sometimes used. A two-rate meter is one that records the power during certain hours of the day separately from the power used in the evening, so that the amount of power to be charged for at the reduced rate may be known. The two-rate meter as brought out by the General Electric Company is a regular Thomson recording meter provided with two dials and recording trains. The meter is also provided with an electrically operated self-winding clock movement that throws either one or the other recording train into gear with the meter at whatever times the clock is set for. For example, the clock might be set so that the meter would record on the low-rate dial from 6 A.M. to 6 P.M. and then be switched over to record on the high-rate dial from 6 P.M. to 6 A.M. The changing over from one dial to the other is accomplished by means of two small friction clutches controlled by the clock.

**110. The Maximum-Demand Meter.**—The maximum amount of current that the various customers consume, to a large extent determines the capacity of the equipment that must be provided for the station. Some customers might use large currents for short intervals, but the plant would have to be capable of delivering these large currents, and in some cases, therefore, the maximum demand for current is taken into account in charging for the supply of current. One style of instrument used for indicating the maximum current used by a customer is the Wright demand meter. In this instrument the main current passes around a flat conductor that encircles a bulb on the top of one branch of a U-shaped tube, which is partly filled with liquid. When current flows through the strip the bulb becomes heated, thus expanding the air and forcing liquid into a bulb on the top of the other branch of the U tube, from which it flows into a vertical tube closed at the lower end. The amount of liquid thus forced into this tube, by the expansion due to the heating effect of the main current, is a measure of the maximum current used by the customer, and this reading, in conjunction with the reading of a regular watt-hour meter, can be used in determining the charge to be made,

## INSTALLATION AND OPERATION OF RECORDING METERS.

**111.** When an electric light or power company supplies power to a consumer, they wish to know the total amount of energy supplied during a given time, say 1 month, rather than the amount of power that the customer is using at any particular time, just as a gas company wishes to know the total number of cubic feet of gas used during the month rather than the number of cubic feet used by the customer at different times during the month. In order to get at this, recording wattmeters or ampere-hour meters are installed. The former read in watt-hours and the latter in ampere-hours. A recording wattmeter records watt-hours and not watts, giving the product of the average number of watts used by the time during which it was used. For example, one day the customer's motors or lights might take 3,000 watts for 10 hours (30,000 watt-hours), and the next day only 1,000 watts for 3 hours (3,000 watt-hours), and so on. The recording wattmeter, or, more properly, the watt-hour meter, averages up all these values, and by taking the reading at the end of the month and subtracting the previous reading, the watt-hours of electrical energy used during the month may be obtained. One kilowatt-hour is equal to 1,000 watt-hours, and since 1 horsepower is equal to 746 watts, 1 kilowatt-hour equals $\frac{1000}{746}$ horsepower-hours. One kilowatt-hour is, therefore, equivalent to about $1\frac{1}{3}$ horsepower expended for 1 hour.

**112.** As stated above, some meters, especially those of the older types, record ampere-hours. It is evident that ampere-hours are not a true measure of the work done, because no account is taken of the voltage. If the voltage can be assumed to be constant, a fairly close estimate of the watt-hours may be obtained by multiplying the ampere-hours by the voltage. In what follows, we will confine our attention to the Thomson recording wattmeter, as this is used more extensively than any other one type.

**113. Installation of Meters.**—Directions are sent out with each particular type of meter, giving points to be observed in setting up and connecting. See that the meter is leveled properly, that the shaft turns freely, and that the commutator and brushes are in good condition. Be sure that it is placed in a position where it will not be subjected to vibration, as this is very liable to injure the jewel and pivot. Mount the meter on a brick wall, if possible, and do not place it near where a door is being continually opened and shut. Also place it where it will not be exposed to dampness, an unusual amount of dust, or chemical fumes of any kind.

**114. Testing Meters.**—Recording wattmeters should be checked up with a standard direct-reading meter occasionally to see if they record correctly. In order to do this, the meter is set to work on a load of lamps, or other convenient resistance, the standard direct-reading wattmeter being connected as shown in either Fig. 47 or Fig. 48. A chalk mark is made on the meter disk, so that the revolutions may be easily counted, and the revolutions are taken for 40 to 60 seconds, the observer using a stop watch. Another observer reads the standard instrument, and the load is kept as nearly constant as possible throughout the test. The meter watts may then be calculated from the following formula:

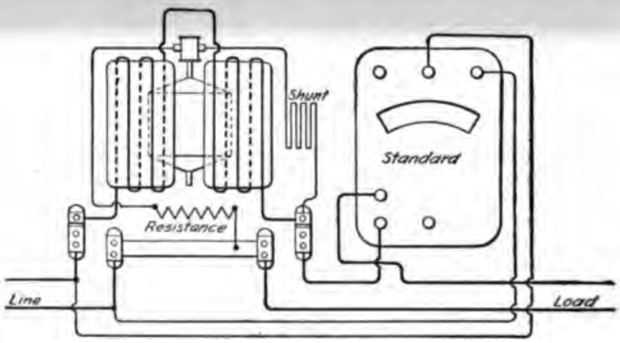


FIG. 47.

$$\text{Meter watts} = \frac{R \times K \times 3{,}600}{T}, \qquad \textbf{(20.)}$$

where

$R$ = number of revolutions in $T$ seconds;
$T$ = time in seconds of $R$ revolutions;
$K$ = constant of meter (this is marked on the meter dial).

The actual watts are obtained from the standard meter, hence the percentage by which the meter is correct is found by dividing the watts as given by formula **20** by the watts as given by the standard meter.

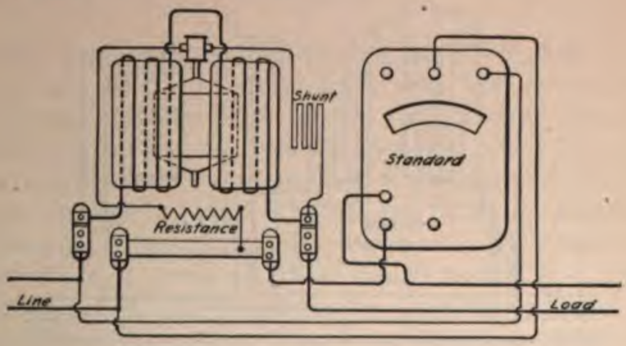


FIG. 48.

EXAMPLE.—The disk of a 10-ampere, 100-volt Thomson meter makes 10 revolutions in 60 seconds. The average standard watts as indicated by the standard meter are 303. Find the percentage error of the recording meter. The constant of the meter is ½.

SOLUTION.—From formula **20,** we have

$$\text{Meter watts} = \frac{10 \times \frac{1}{2} \times 3{,}600}{60} = 300.$$

$$\tfrac{300}{303} = .99, \text{ or } 99\%. \quad \text{Ans.}$$

The meter is, therefore, 1 per cent. too slow, and the damping magnets should be shifted in a little so that the retarding action on the disks will not be so great.

**115.** If a standard wattmeter is not available for testing purposes, separate ammeters and voltmeters may be used for direct-current work, but they are not as convenient.

In Figs. 47 and 48, it will be noticed that the energy consumed in the potential circuit of either meter is not measured by the other; that is, the current in the armature of the Thomson meter does not pass through the fields of the standard meter; neither does the current in the shunt of the standard pass through the field coils of the Thomson meter.

**116.** To test a meter used on a three-wire 110- to 220-volt circuit it may be connected as shown in Fig. 49. The potential circuits of these meters are wound for 110 volts. The field coils can, therefore, be connected in series, and the standard meter connected in as shown in Fig. 49. In formula **20,** however, $K$ should only be taken as one-half the constant marked on the dial. Aside from this, the meter can be tested in the same manner as a two-wire meter.

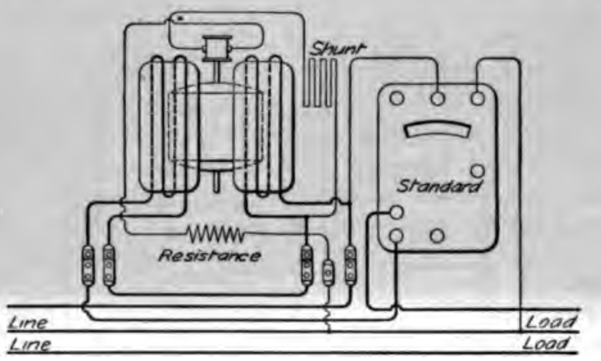


FIG. 49.

**117. Cleaning Meters.**—The first thing to be done in cleaning meters is to blow out the dust. A small syringe is useful for this purpose. Parts that can be reached should be wiped out with a cotton cloth. Clean the top bearing and worm-gear, but do not oil them, as the oil is liable to find its way on to the commutator. If the train of the counter is stiff, give it a bath in gasoline. Next see that the brushes present a clean, flat, smooth surface to the commutator. A piece of crocus cloth glued to a narrow, thin stick answers for polishing the brushes, except in cases where grooves are worn in them. If this is the case, a small fine-grained file may be used before polishing. After the brushes are put in proper shape, the commutator should be polished with a narrow strip of cotton tape, or, if necessary, a worn strip of crocus cloth. To use the crocus cloth or tape, pass it around the commutator, cross the ends in front to prevent catching the brushes, then pull the strip back and forth, at the same time twirling the rotating part. The spaces between the commutator segments can be cleaned out with a stick whittled to a thin, flat point.

**118.** The jewel and pivot on the lower end of the shaft should next be carefully examined. The jewel can be tested with a fine-pointed needle, and if found rough or scratched, it should be replaced by a new one. The shaft end or pivot may be removed with a special tool provided for the purpose, screwed into the end of an old shaft, and any roughness detected by rubbing it over the finger nail. If found rough, a new shaft end should be put in. A drop of good clock oil may be put on the jewel, except when the meter is in a dusty place. Sometimes the armature circuits of meters become broken, in which case the meter will not come up to speed even with the magnets swung in as far as they will go. Again, if the meter cannot be brought down to the proper speed, the magnets may be too weak or there may be a short circuit in the resistance in the back of the meter, thus letting too much current through the armature.

**119. Reading Meters.**—Reading meters is considered a difficult task by many, but once the dials are thoroughly understood there should be no trouble in reading correctly. The dials on a recording wattmeter bear a considerable resemblance to those on a gas meter. The arrangement differs somewhat with different makes, but if one is able to read the Thomson meter correctly, there should be little difficulty with the others.

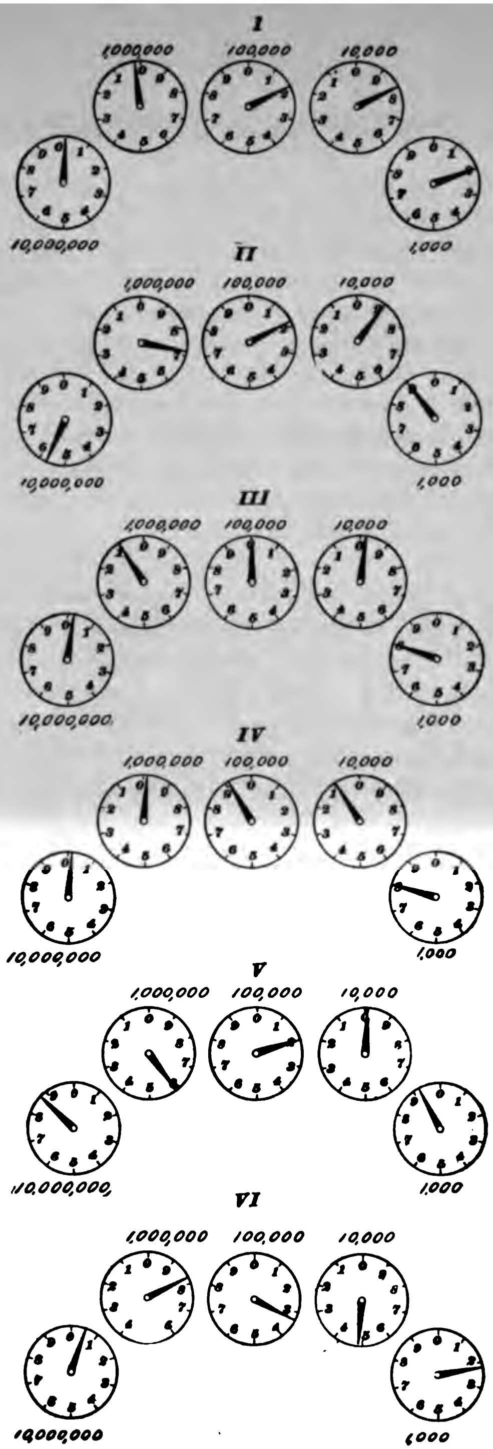

I
1,000,000
100,000
10,000
10,000,000
1,000
II
1,000,000
100,000
10,000
10,000,000
1,000
III
1,000,000
100,000
10,000
10,000,000
1,000
IV
1,000,000
100,000
10,000
10,000,000
1,000
V
1,000,000
100,000
10,000
10,000,000
1,000
VI
1,000,000
100,000
10,000
10,000,000
1,000

FIG. 50.

**120.** The Thomson meter has five dials. The lowest reading pointer is the one to the extreme right (facing the meter); it is marked 1,000, and this means that *one complete revolution* of the hand indicates 1,000 watt-hours, and each division, therefore, represents 100 watt-hours. The next one to the left is 10,000 to a revolution, or 1,000 for a division, and so on. Fig. 50 shows six different readings, and by studying these, the student should be able to take readings from any meter. Some of these figures have the hands in positions that are liable to puzzle the beginner.

Beginning at the left, number the pointers 1, 2, 3, 4, and 5. Then, in *I*, Fig. 50, pointer 5 is on *2* and is read "200." Pointer 4 is two-tenths of the way between *8* and *9* and is read "8,000." Pointer 3 is read "10,000." Pointer 2 has not gone through its first division; likewise pointer 1. The statement of the meter is then 18,200, and is to be multiplied by the constant of the meter to reduce to watt-hours.

The statement of *II* is 5,718,900 (not 5,719,900, as it frequently would be read). Pointer 4 should not be read "*9*" until pointer 5 has completed its revolution and is again at *0*.

The statement of *III* is 99,800 (not 109,800), because the 100,000 mark will not be reached until pointer 5 has passed from *8* to *0*, when 4 and 3 will be at *0*, pointer 2 at *1*, and pointer 1 just past the zero mark.

The statement of *IV* is 9,990,800. Pointer 1 is slightly misplaced. Otherwise, the reasons given above will apply to this statement.

The statement of *V* is 8,619,900. Pointer 2 is misplaced; for it should be two-tenths of the way between *6* and *7* instead of nearly over *6*, as shown.

The statement of *VI* is 835,200 (not 834,200). Pointer 4 is misplaced. It should be about the same distance on the other side of *5*. These misplaced hands are frequently met with in practice and are generally caused by a knock in removing the cover, or, perhaps, they are a little eccentric.

**121. Rule.**—*To ascertain the number of watt-hours that have been used by a consumer from one date to another, subtract the earlier statement from the latter and multiply by the constant of the meter.*

Sometimes no constant is marked on the meter, in which case the reading as taken from the dial is watt-hours, or, in other words, the constant is 1.

EXAMPLE.—Suppose the statements as given by Fig. 50 were taken at the following dates:

Statement January 30 $(V) = 8,619,900$.
Statement February 28 $(IV) = 9,990,800$.
Statement March 31 $(I) = 18,200$.

The constant of the meter is supposed to be ½.

SOLUTION.—The watt-hours supplied between January 30 and February 28 $= (9,990,800 - 8,619,900) \times \frac{1}{2} = 685,450$. Some prefer to first multiply each reading by the constant and then subtract as follows: $\frac{1}{2} \times 9,990,800 - \frac{1}{2} \times 8,619,900 = 685,450$.

The watt-hours supplied between February 28 and March 31 are obtained as follows: It will be noticed that 10,000,000 is the highest reading of the meter and that between the two above dates the meter has run up to its highest point and has registered 18,200 anew. The watt-hours will therefore be

$$(10,000,000 - 9,990,800) \times \tfrac{1}{2} + 18,200 \times \tfrac{1}{2} = 13,700. \quad \text{Ans.}$$

# ELECTRIC TRANSMISSION.

(PART 2.)

## LINE CONSTRUCTION.

**1. Line construction** may be considered conveniently under two heads: (*a*) *overhead construction;* (*b*) *underground construction.*

For nearly all work in towns and small cities or for cross-country work, the lines are supported on poles. In cities, the current is now usually distributed, at least so far as the central part of the cities is concerned, by means of wires or cables run in underground tubes or ducts. This method is, of course, much more expensive than the overhead method; but the large increase in the number of wires used for different electrical purposes has rendered underground distribution in cities almost absolutely necessary.

### OVERHEAD CONSTRUCTION.

#### POLES.

**2. Selection of Poles.**—The poles used to the greatest extent in this country are of the following kinds of wood: white cedar, Norway pine, chestnut, and cypress. The average lives of these, under average conditions, are placed by good authority at the following values:

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| | |
|---|---|
| Norway pine | 6 years. |
| Chestnut | 15 years. |
| Cypress | 12 years. |
| White cedar | 10 years. |

Cedar poles are undoubtedly used to the greatest extent. Considering their strength, they are light in weight, and, by some authorities, are considered the most durable, when set in the ground, of any American wood suitable for pole purposes.

**3. Sizes of Poles.**—The best lines in this country use no poles having tops less than 22 inches in circumference. If the poles taper at the usual rate, the specification that a pole shall have a top 22 inches in circumference, or approximately 7 inches in diameter, is usually sufficient, for the diameter at the butt will then be approximately correct, no matter what may be the length of the pole.

**4.** Where a pole line is to carry but few wires, it is unnecessary to make the poles so heavy, and in many cases poles with a 5-inch top will answer every purpose. In determining the height of poles, several considerations must be borne in mind. The number of wires to be carried, and therefore the number of cross-arms, determines to some extent the general height of the pole to be used.

**5. Spacing of Poles.**—Practice varies as to the spacing of poles. Of course, the number and sizes of the wires to be carried is the most important consideration in determining this point, but the climatic conditions, especially with regard to heavy wind and sleet storms, should also be considered. In general, it may be said that the best lines carrying a moderate number of wires use 40 poles to the mile, while for exceptionally heavy lines, the use of 52 poles to the mile, or one pole every hundred feet, is not uncommon practice. As a general rule, which it is safe to follow in the majority of cases 35 or 40 poles to the mile should be used. For city work, the poles should be set on an average not farther apart than 125 feet.

### CROSS-ARMS.

**6.** The cross-arms should be made of well-seasoned, straight-grained, Norway pine, yellow pine, or creosoted white pine. Cross-arms are made in standard sizes, the length of the arm depending on the number of pins it is intended to hold. The standard cross-arm is 3¼ × 4¼ inches, and varies in length usually from 3 to 8 feet. They are usually bored for 1½-inch pins and provided with holes for two ½-inch bolts. The arms are generally braced by flat, iron braces, about 1¼ inches wide by ¼ to ⅜ inch thick. These braces are shown in Fig. 1, which gives a view of an ordinary pole top provided with two 4-pin cross-arms.

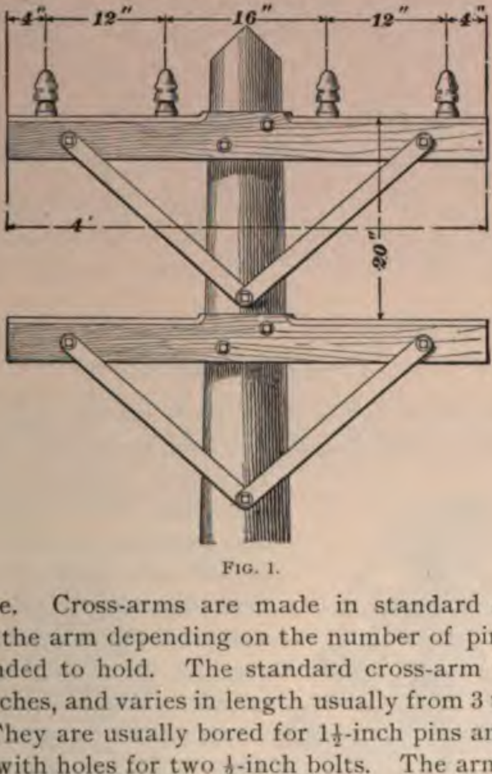

FIG. 1.

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### PINS.

**7.** The pins by which insulators are mounted upon cross-arms are shown in Fig. 2. They may be made of locust, chestnut, or oak (the woods being

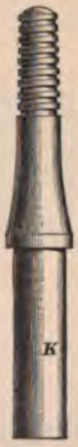

FIG. 2.

preferred in the order named), and are turned with a coarse thread on the end on which the insulator is to be secured. The shank *K* is turned 1½ inches in diameter.

The pin should be secured in the hole by driving a nail through the arm and the shank of the pin. This renders it difficult to extract the shank of the pin in case a new one is required; but, on the other hand, it prevents the pin pulling out, which sometimes occurs when this precaution is not taken. For heavy lines, pins are used that have an iron bolt passing through them. Fig. 3 shows a pin for this kind designed by F. Locke, with a heavy insulator for carrying a cable in the groove *a*.

## INSULATORS.

**8. Insulators** in this country are usually made of glass, while in Europe porcelain is more commonly used. Porcelain, when new, is a better insulator than glass; but it is more costly, and under the action of cold the glazed surface becomes cracked. When this happens, the moisture soaks into the interior structure, and its insulating quality is greatly impaired. Tests recently made have shown that when newly put up, the insulation resistance of porcelain insulators is from 4 to 8 times better than glass, but that along railroads and in cities smoke forms a thin film upon each material, so that at the end of a few months their insulating properties are nearly alike. On country roads, away from railroad tracks, the porcelain insulators maintain a higher insulation than the glass during rain storms, but in fine weather it is not so high. Porcelain has an

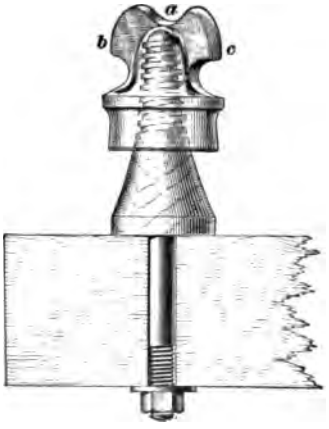

FIG. 3.

advantage over glass in that it is not so brittle, and, therefore, less likely to break when subjected to mechanical shocks. Porcelain does not condense and retain on its surface a thin film of moisture so readily as glass, i. e., it is less hygroscopic. On the other hand, however, glass insulators are not subject to such an extent as porcelain to the formation of cocoons and cobwebs under them, the transparency of the glass serving to allow sufficient light to pass through the insulator to render it an undesirable abode for spiders and worms. As cocoons, cobwebs, etc. serve to lower the insulation of the line to a great extent, this is an advantage that, in this country, it is not well to overlook.

**9. Types of Insulators.** — For ordinary work with moderate pressures, glass insulators are used. The style of insulator will depend to some extent on the size of wire to be supported. Most power-transmission lines are of weather-proof wire or cable; wires smaller than No. 6 or 8 B. & S. are seldom put up, hence the glass insulators, as a rule, must be heavier than the kind used for telegraph or telephone work. Fig. 4 shows an insulator, known as the D. G. (deep groove), that is well adapted for ordinary lines. This insulator is so called to distinguish it from those with smaller grooves, such as are used for telephone or telegraph work. It is provided with two petticoats, or flanges, *a*, *b* over which leakage must take place before the current can

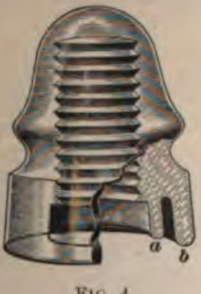

FIG. 4.

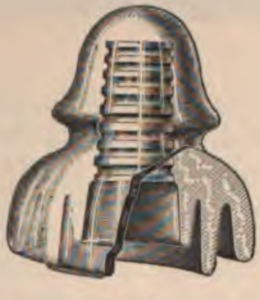

FIG. 5.

leak from the wire to the pin. The use of a number of petticoats increases the leakage distance and provides a high insulation. Insulators used on high-tension lines are provided with a number of such petticoats. When heavy cables are used, it is customary to carry them on especially heavy insulators and to tie down the cable on top of the insulator instead of tying it to the side. Fig. 3 shows a common type of such insulator. The cable rests in the groove *a* and is held in place by a tie-wire twisted around the cable and passing under the ears at *b*, *c*. Good quality glass insulators, such as those just described, may be used for any lines where the potential is not over 2,000 or 3,000 volts. For higher pressures on transmission lines, it is better to use a larger insulator giving a higher degree of insulation.

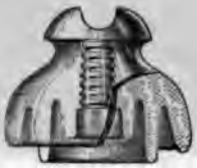

FIG. 6.

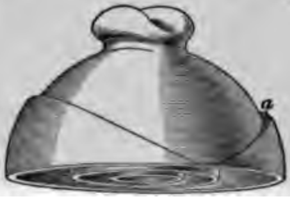

FIG. 7.

Fig. 5 shows a Locke insulator of glass that is suitable for any pressure up to 5,000 volts. This insulator is 4½ inches in diameter, and it will be noted is provided with three petticoats, thus giving a long leakage distance from the wire to the pin. Fig. 6 shows a still larger insulator; this one is suitable for pressures up to 25,000 volts and is 5½ inches in diameter. For high pressures, porcelain insulators have been largely used; as yet there does not seem to be any settled opinion as to just which is the better, glass or porcelain, for this kind of work. Fig. 7 shows a type of porcelain insulator that is used extensively in connection with the Niagara transmission plant. These insulators are elliptical, or "helmet," shaped and have an eave, or ridge, *a* on each side. The object of these ridges is to run off the water to the end of the insulator, where it will drop clear of the cross-arm. These extra large insulators are only necessary for the high-tension lines, and by far the greater part of electric-light lines are carried on ordinary glass insulators of the type shown in Figs. 3 or 4.

### TYING AND SPLICING.

**10. Tying.**—Fig. 8 shows the method of tying that is commonly used. The tie-wire *a* is usually from 12 to 16 inches in length and should be insulated to the same extent as the wire to be tied. The line wire is laid in the groove of the insulator, after which the two ends of the tie-wire, which have been passed half way around the insulator, are wrapped tightly around the wire. Some linemen advocate the plan of starting to wrap one end of the tie-wire over and the other end under the line wire. Fig. 9 shows a method of tying that is used where the wire lies on top of the insulator.

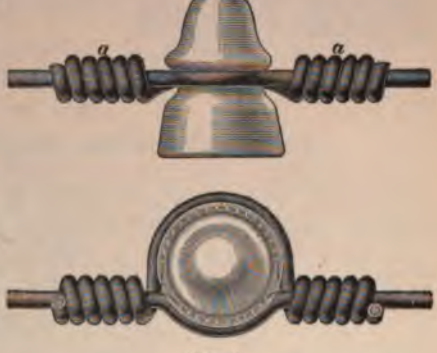

FIG. 8.

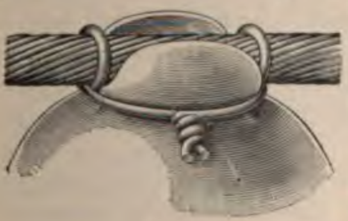

FIG. 9

**11. Splicing.**—The American wire joint shown in Fig. 10 is generally used where splices must be made. The wires are placed side by side and each end wound around the other. All joints should be soldered. The rules of the National Board of Fire Underwriters require that all line joints shall be mechanically and electrically perfect before being soldered; i. e., solder should not be depended on to make the joints strong mechanically or efficient as an electrical conductor. In other words, soldering should always be done simply as a safeguard against any diminution in

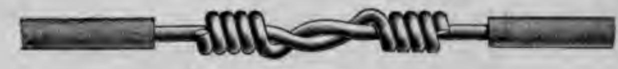

FIG. 10.

the electrical conductivity of the joint. Large cables are joined either by weaving the strands together and soldering or by using a copper sleeve into which the ends of the cable are fastened.

## UNDERGROUND CONSTRUCTION.

**12.** In cities, it is necessary to place the wires underground, especially in the business districts. The best way to do this is to provide a regular tunnel, or **subway**, in which the various wires, or cables, can be placed and which will be large enough to allow a man to walk through for inspection or repair. This method is, however, very expensive and can only be used in a few very large cities. Another method is to use **conduits** through which to run the cables. These conduits usually consist of tubes of some kind that are buried in the ground and thus provide ducts into which the cables may be drawn. These ducts terminate in **manholes,** usually placed at street intersections, by which access may be had to the cables and from which they may be drawn into or out of the ducts. A third method, and one that has been largely used in cities for distributing current for lighting purposes, is to bury tubes containing insulated conductors in the ground. In this system the conductors cannot be withdrawn, as in the conduit system, and there is a separate tube for each set of conductors. The Edison tube system belongs to this variety, and a very large amount of lighting on the three-wire system has been carried out by using underground conductors of this kind.

### CONDUITS.

**13.** A large variety of **conduits** are in use, and it has not been definitely settled as yet just which type is the best; but the following will serve to give an idea as to some of the more common forms that have stood the test of actual work and are in extended use.

**14. Creosoted-Wood Conduit.**—A form of conduit largely used, and which has the advantage of being very cheap to install, is one that is composed of sections of wooden tubing, the fiber of the wood being impregnated with creosote, in order to prevent its decay. This form of conduit is commonly known as **pump-log conduit,** on account of the resemblance of the wooden sections to the ordinary form of wooden pump logs. A section of this conduit is shown in Fig. 11; the ends are doweled in order to preserve the proper alinement in joining. These sections are usually 8 feet in length, and have circular holes through their centers from 1½ to 3 inches in diameter, according to the size of cable to be drawn in. The external cross-section is square and 4½ inches on the side, in the case of a tube having a 3-inch internal diameter. Such a conduit as this, if properly impregnated with creosote, will probably have a life of from 15 to 20 years, and perhaps much longer, this point being one concerning which there is considerable argument and which, probably, time alone will decide. In some cases, difficulty has been experienced with creosoted-wood conduits on account of the creosote attacking the lead covering of the cables.

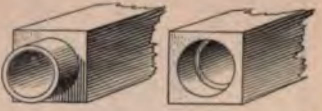

FIG. 11.

**15. Cement-Lined Pipe Conduit.**—This conduit, made by the National Conduit and Cable Company, is now largely used for underground wires. The sections shown in Fig. 12 are usually 8 feet long and are made as follows: A tube is made of thin wrought iron, No. 26 B. W. G., .018 inch thick and securely held by rivets 2 inches apart. The tube is then lined with a wall of Rosendale cement ⅝ inch thick, the inner surface of which is polished while drying, so as to form a perfectly smooth tube. This tubing comes in three sizes, each having a length of 8 feet and internal diameters of 2, 2½, and 3 inches, the latter being the standard size. Each end is provided with a cast-iron, beveled socket joint, by the use of which perfect alinement may be obtained by merely butting the ends together. These beveled socket joints also allow of slight bends being made in the line of conduit as it is being laid.

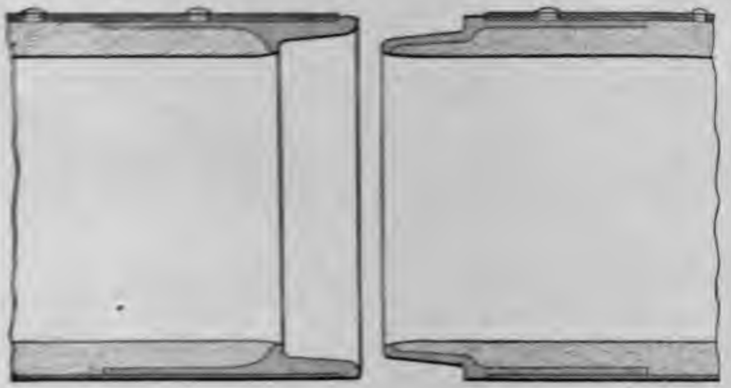

FIG. 12.

**16. Vitrified-Clay or Terra-Cotta Conduit.**—A form of conduit that is probably used in good construction work to a greater extent than any other is made of vitrified clay. This material has the advantage of being absolutely proof against all chemical action, and unless destroyed by mechanical means will last for ages. Besides this, its insulating properties are high and it is comparatively cheap and easily laid.

When clay conduits were first used, it was customary to form various sections with two or more ducts, one of the most common form being the 4-duct type, two sections of which are shown in cross-section in Fig. 13. These are made with 2, 3, 4, 6, and 9 ducts, all in 8-foot lengths. In another form, each section had 2 ducts only, these ducts being large enough to accommodate several cables. In this form, however, much trouble has been experienced, due to the fact that when several cables are laid in a single duct, it often becomes impossible to withdraw them, owing to the fact that they are much more likely to become wedged than in the forms where one cable only occupies a single duct. It is not good practice to put more than one cable in the same duct.

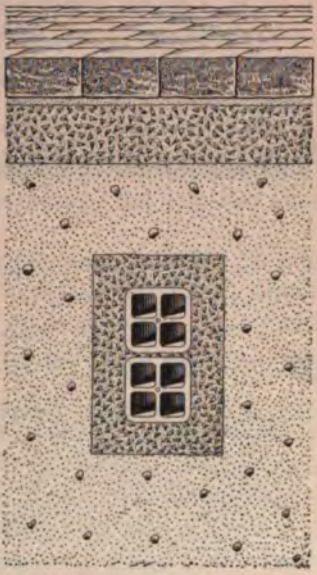

FIG. 13.

**17.** The form of clay conduits now most commonly used is shown in Fig. 14, this being usually made in 18-inch lengths, having an internal diameter of from 3 to 3¼ inches and being 4⅝ inches square outside. This duct has a great advantage over the multiple-duct sections in the greater ease of handling and also in the fact that it is much less liable to become warped or crooked in the process of burning during its manufacture than the larger and more complicated forms. Like the cement-lined pipe, it is laid on a bed of concrete, cemented

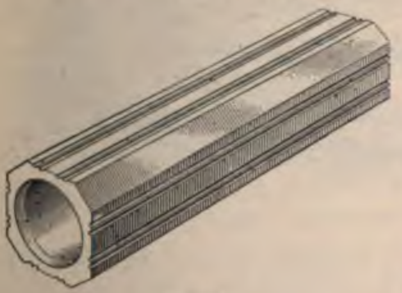

FIG. 14.

together with mortar, and enclosed on all sides and on top by concrete. In laying, a wooden mandrel, such as is shown in Fig. 15, 3 inches in diameter and about 30 inches in length, is used. At one end is provided an eye *a*, which may be engaged by a hook, in order to draw it through the conduit, while at the other end is secured a rubber gasket *b* having a diameter slightly larger than that of the interior of the duct. One of these mandrels is placed in each duct when the work of laying is begun. As the work progresses, the mandrel is drawn along through the duct by the workmen, by means of an iron hook at the end of a rod about 3 feet long, the method of doing this being shown in Fig. 16. By this means, the formation of shoulders on the inner walls of the ducts at the joints is prevented, and any dirt that may have dropped into the duct is also removed. The

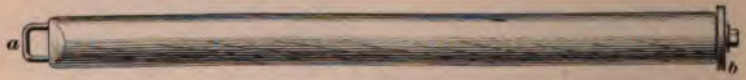

FIG. 15.

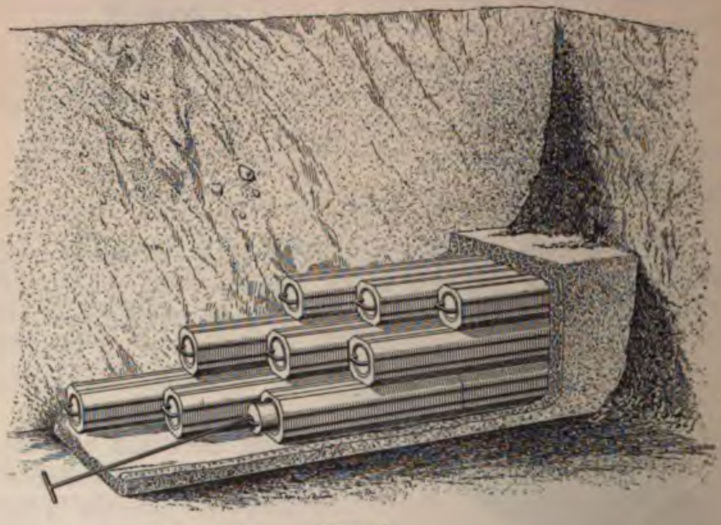

FIG. 16.

cylindrical part of the mandrel insures good alinement of the ducts, thus securing a perfect tube from manhole to manhole.

**18.** Fig. 16 illustrates the method of laying this conduit, and shows how the joints should be broken in the various layers so as to insure a maximum lateral strength to the structure.

All conduits should be laid to such grades that there will be no low points or traps in the conduit that will not drain into the manholes.

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### MANHOLES.

**19. Manholes** form a very important part in cable systems and require careful designing to properly adapt them to the particular conditions to be met. They are usually placed about 400 feet apart, and if possible, at the intersection of streets. They should be located with a view to making the line of conduit between them as nearly straight as possible. The size of the manhole will depend on the number of ducts that are to be led to it, as well as the number of men that will be required to work in it at one time. Manholes 6 feet square and from 5 to 6 feet high will usually be required for large systems, while for smaller systems, or the outlying portions of large ones, they may be made as small as 4 feet in length, in the direction of the conduit, 3 feet wide and 3 or 4 feet high.

**20.** Manholes may be constructed of either cement or hard-burned brick laid in Portland-cement mortar, the latter, probably, being preferable. The foundation should consist of a layer of cement, the concrete being at least 6 inches thick. The walls, if of brick, should be laid in cement mortar, and should, also, be thoroughly plastered on the outside with the same mortar. They should never be less than 8 inches thick, and should be made double this thickness where large manholes are being constructed in busy streets. As the brickwork is laid up, the iron brackets for supporting the cables around the sides should be built in. The roof should be of either arched brick or structural iron, supporting some form of cast-iron manhole cover, of which there are several types on the market.

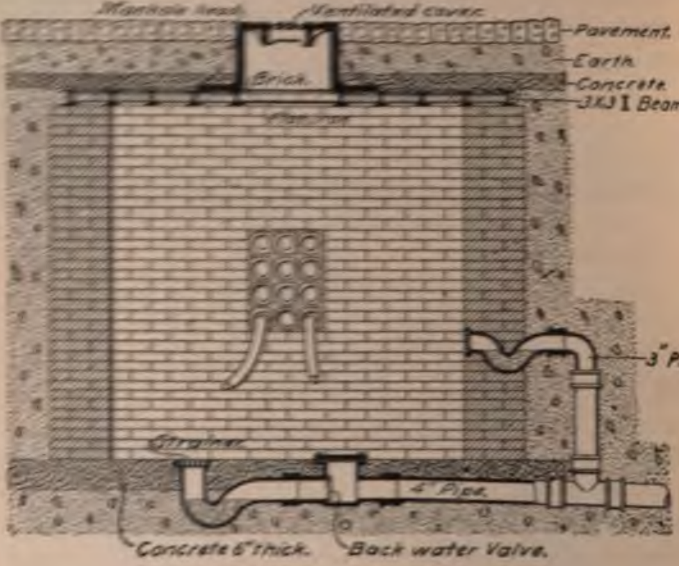

FIG. 17.

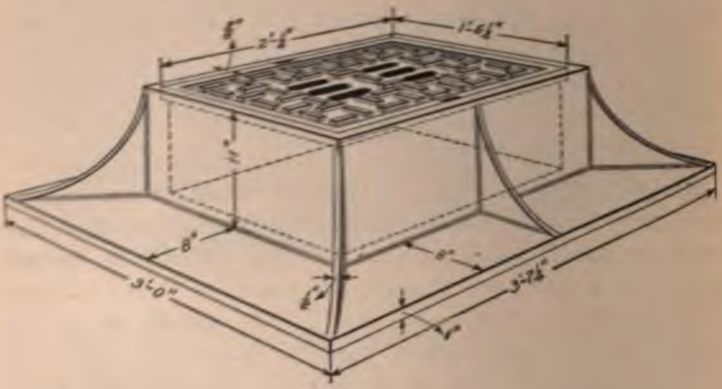

FIG. 18.

**21.** Fig. 17 shows a cross-section of a ventilated manhole well suited for ordinary power-distribution work. It has been found better, on the whole, to provide manholes

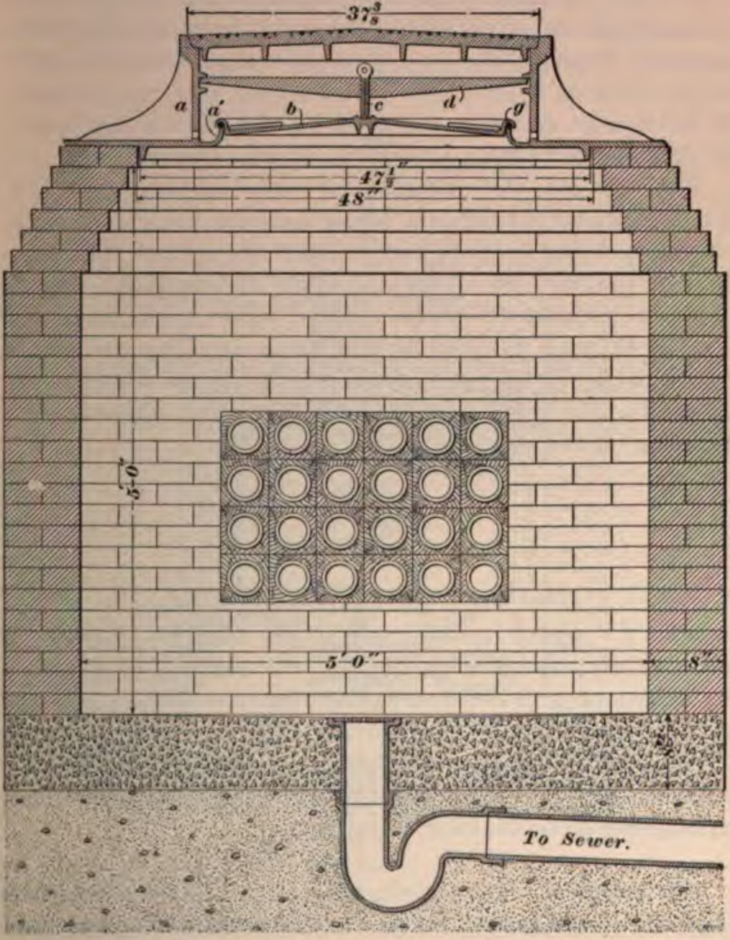

FIG. 19.

with ventilated covers and good sewer connections than to close them up tight, as was formerly done. If they are tightly sealed, gases are liable to accumulate and cause explosions. In Fig. 17, the manhole is provided with two sewer connections, so that in case the bottom one gets clogged up, the water will be able to flow through the side connection instead of backing up into the ducts. Both connections are provided with traps to keep out the sewer gas and the bottom connection is equipped with a back-water valve to keep water from backing into the manhole. A removable cover is provided at the back-water valve, so th t that accumulates may be cleaned out.

roof of the manhole is made by laying 3″ × 3″
ross the top and filling between them with brick,
being covered with a layer of cement. The man-
er may be either round or rectangular. Fig. 18
rectangular manhole head with ventilated cover.
s a manhole with a water-tight inner cover *b*,
ed down by the screw *c* and cross-
ight by the gasket *g*

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DISTRIBUTION FROM MANHOLES.

**22.** As stated before, where the conduit system of underground distribution is used, the current is delivered by means of lead-covered cables that are drawn into the ducts after the conduit proper has been completed. These cables are drawn from manhole to manhole by means of a rope attached to the end of the cable. Fig. 20 shows one arrangement for drawing in cables.

**23. Cables.**—The construction of the cables themselves depends on the kind of service to which they are to be put. Two kinds of insulation are available—rubber and paper. With good rubber insulation, a small puncture in the lead sheath may not impair the insulation for some time, because the rubber is, to a large extent, proof against moisture. On the other hand, paper insulation will be damaged if the lead sheath becomes punctured so as to admit moisture. Paper insulation is, however, cheaper than rubber, and if the cables are carefully installed will give excellent service. Fig. 21 shows a paper-insulated cable designed for 6,600-volt, three-phase transmission. The three conductors are insulated with paper wrapping to a thickness of $\frac{1}{8}$ inch.

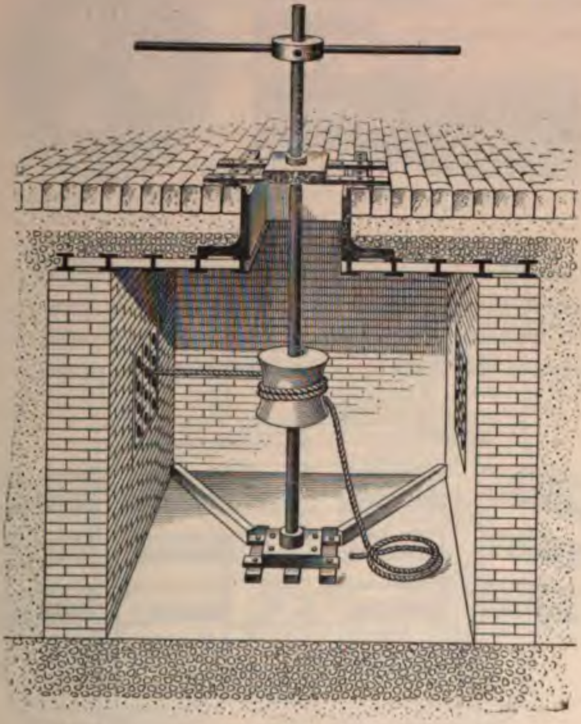

FIG. 20.

These three strands are then twisted together and covered with a wrapping of paper $\frac{1}{16}$ inch thick, over which the $\frac{1}{8}$-inch lead covering is forced. The paper is treated with insulating compound and the space between the strands, shown black in the figure, is filled with jute treated with insulating compound.

**24. Connecting Cables.**—In underground, electric-power distribution, it is important to have the various parts of the system so arranged that they can be disconnected, if necessary, because faults are liable to develop, and if the various sections can be readily disconnected, it makes the location of the defective portion very much easier to find. Also, when the defective part is located, it can easily be cut out without interfering with the operation of the remainder of the system. For ordinary low-pressure work, the various joints are usually made by means of **coupling boxes,** or **junction boxes.** These are placed on the side walls of the manholes and are made water-tight. Fig. 22 shows a coupling box. *A*, *B*, and *C* are the three main cables, or feeders, of a three-wire system that are to be

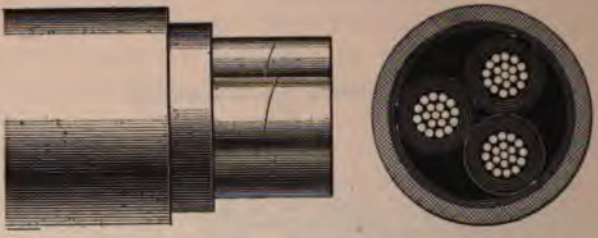

FIG. 21.

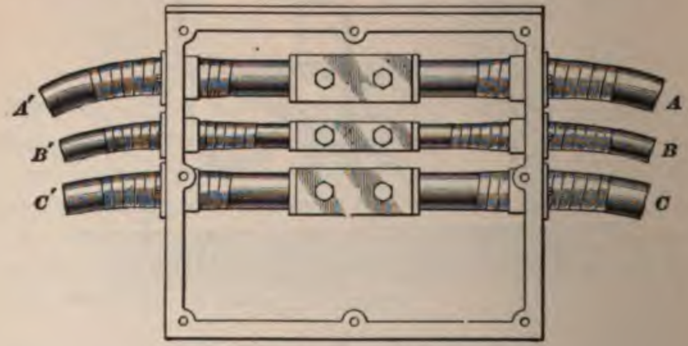

FIG. 22.

coupled to the three cables *A'*, *B'*, *C'*. The cables enter the cast-iron box through rubber gaskets that are clamped so as to make the box water-tight. Each cable is provided with a terminal on the end, and these terminals are connected together by pieces of copper bar securely clamped against the terminals by the bolts shown in the figure. The box is provided with a cover that is bolted against a rubber gasket. This box is merely intended for coupling the ends of the cables together and takes the place of permanent joints that could not readily be disconnected.

**25. Junction Boxes.**—The main cables, or feeders, running from the station terminate in the manholes, and it is necessary to have some convenient means of connecting them to the various branch lines. This is done by means of junction boxes. Fig. 23 shows a junction box that is known as a *four-way box*, because it accommodates four positive and

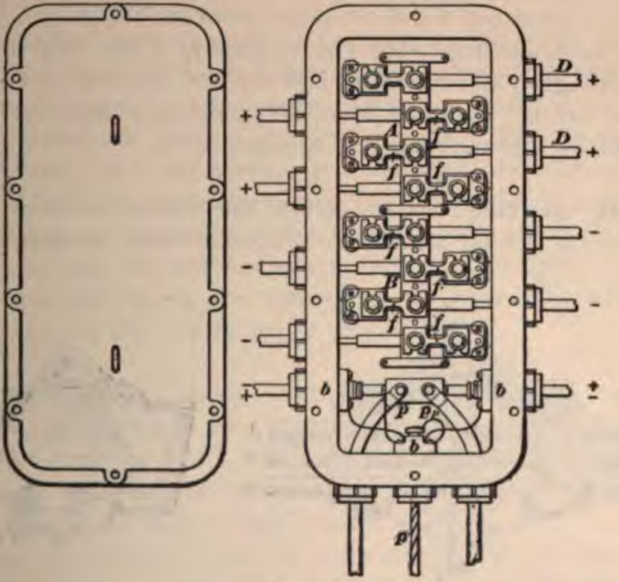

FIG. 23.

four negative cables. The box is designed for use on low-pressure, three-wire work. *A* and *B* are the positive and negative bars, which are made of copper and are well insulated from each other. These bars connect across to the cable terminals through copper fuses *f*, so that in case a short circuit occurs on a line, these fuses will blow and thus prevent damage. The short neutral bar shown in the bottom of the box attaches directly to the cables, because it is not usually considered necessary or even desirable to place a fuse in the neutral. The small wires *p*, *p* are **pressure wires** that run back to the station and there connect to voltmeters, so that the voltage at the center of distribution, represented by the junction box, may be determined at any time. These pressure wires are protected by fuses placed in the small fuse receptacles *b*, *b*, *b*. Each pressure wire connects to one side of a cut-out *b* and the other sides connect to the +, −, and neutral bars. The cables pass into the box through water-tight rubber gaskets and the box is closed by a water-tight cover. Junction boxes are made in a large variety of forms for different kinds of service.

**26. Service Boxes.**—When the conduit system of distribution is used and where customers have to be supplied, small **handholes** are provided wherever distributing points may be necessary. These are much smaller and shallower than manholes and only run down as far as the conduit.

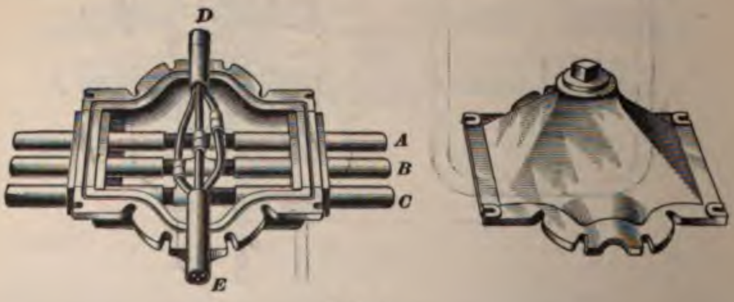

FIG. 24.

In these handholes a **service box** is placed. Fig. 24 shows one style of service box with its cover removed. *A*, *B*, and *C* are the main cables that run straight through the box without being cut. *D*, *E* are the three-wire, branch-service cables, or tubes, for supplying current to the buildings. These are attached to the main cables by means of suitable clamps, and after the cover is bolted in position the box is filled with insulating compound. Fig. 25 shows another style of service box for use on the three-wire system. In this four-way box the main cables are fastened to terminals instead of passing straight through. Fig. 26 shows a handhole with its service box arranged for delivering current to overhead conductors. The main feeders, running from manhole to manhole, are placed in the lower tiers of conduits, and the service mains that run back from the manholes are run in the upper row, so that they will be accessible for the connection of service boxes.

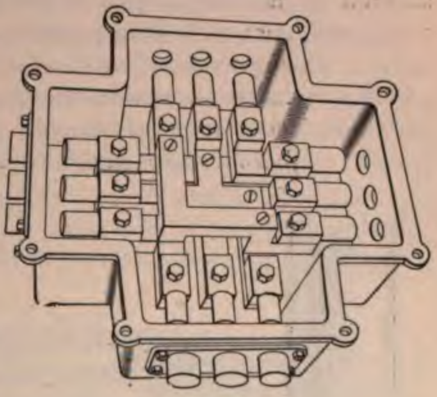

FIG. 25.

**27. Joining Cables.**—For low-pressure work, cables are usually joined in the manholes by means of coupling boxes or junction boxes. Sometimes, however, joints must be made without the use of these boxes, in which cases the job must be very carefully done.

First, the soldered end of the cable is cut off and the cable carefully examined for moisture. If a little moisture be present and there is still more than enough room for the joint, it is allowable to cut off another short length. If indications of moisture are still present, heat should be applied to the lead covering, starting from a distance and proceeding along the cable to the end. Thus the moisture is driven out at the cut. When the use of torches is not allowed on account of gas in the manholes, hot insulating compound, such as boiling paraffin, may be poured over the cable. This process is known as boiling out. To ascertain whether moisture is present, the piece last cut off is stripped of its lead covering and plunged into hot insulating compound. If bubbles rise, moisture is still present.

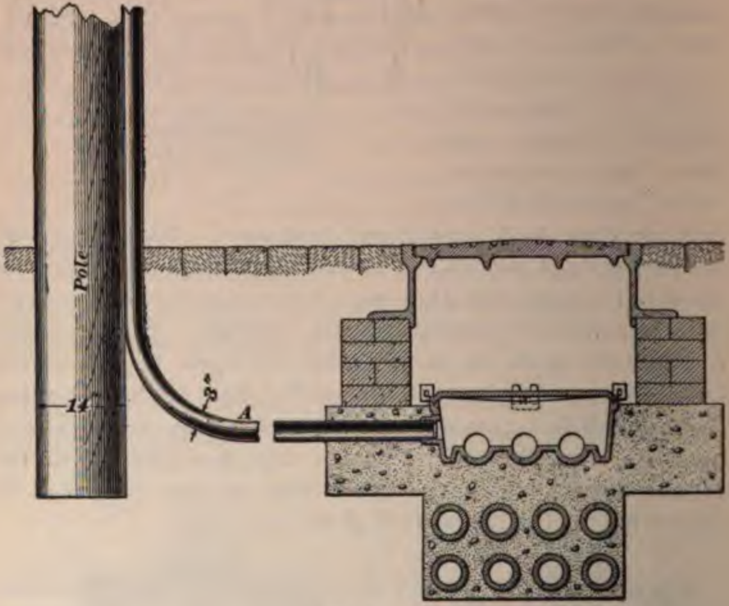

FIG. 26.

When all trace of moisture has disappeared, the lead covering is removed for a convenient length from each of the ends to be joined and the insulation is cut away for a shorter distance from the end, leaving a certain length beyond the lead. A lead tube of sufficient diameter to fit over the cable sheath and of a length great enough to cover the joint to be made is slipped over one end of the cable and back out of the way. Now, if the conductor be small enough, the regulation telegraph joint is made and soldered. But if the conductor be stranded or of large cross-section, the ends are cut square, butted together, and soldered, and made much more secure by a copper sleeve, which is soldered over all. This sleeve is open at one side, so that solder may be run in until the strands are thoroughly saturated. The joint is now covered with insulating tape to the height of the lead covering.

A layer of paraffined paper may be wrapped on over this or, as is sometimes done, a mica tube may be slipped over the joint. The lead tube is then slid along the cable so as to cover the joint. The ends of this are then secured to the cable sheath by a wiped solder joint, thus making the sheath again continuous.

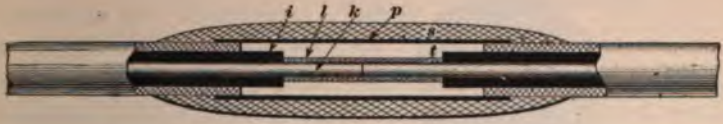

FIG. 27.

A section of such a joint is shown in Fig. 27, where *i* is the insulation, *l* is the copper sleeve, *k* is the conductor, *p* is the paper wrapping or mica sleeve, and *s* is the lead sleeve with a wiped solder joint. The space *t* is wound with insulating tape. For many of the larger cables, the sleeve *s* is made considerably larger in diameter than the cable sheath, so as to leave a space that is afterwards filled with compound. Details as to the methods of splicing and handling the various kinds of cables are furnished by the manufacturers.

**28. High-Tension Joint.**—In most cases where cables are called upon to stand a high pressure, they are joined somewhat as described in the last article and very carefully insulated, so that the insulation of the joint may be as good as that of the rest of the cable. Mechanical couplings and junction boxes are not used very extensively for this class of work on account of the difficulty of securing high enough insulation, and also on account of the difficulty of keeping moisture out of the cable. Figs. 28 and 29 show the Tailleur high-tension coupling that has been successfully used on pressures not exceeding 5,000 volts.

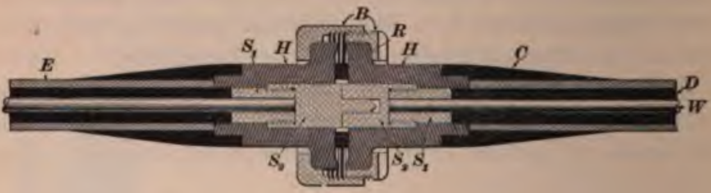

FIG. 28.

Fig. 28 shows the joint made and Fig. 29 shows it broken. To make the joint, the lead armor, or sheath, $E$ is stripped a sufficient distance from the end to permit the slipping on of the hard-rubber jacket $H$, after the terminal $S_1$ has been soldered to the copper conductor $W$, first tinning the end of the copper conductor $W$ and also the terminal $S_1$. One part of the hard-rubber jacket $H$ is slipped through one

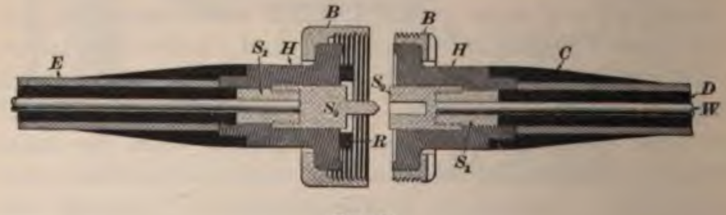

FIG. 29.

part of the brass coupling $B$, then the hard-rubber jacket $H$, with the brass coupling $B$, is passed over the terminal $S_1$, and the piece $S_2$ is screwed on contact terminal $S_1$. Pure rubber, which generally comes in sheets, is cut into strips about 1 inch or 1¼ inches wide, and the joint is taped as shown at $C$, allowing the tape to lap over the cable armor about 1 inch. The rubber tape is afterwards covered with other tape and then treated with compound. The soft-rubber ring *R* is then placed as shown, and the joint clamped tightly together, after which the whole joint is covered with tape and insulating compound.

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### EDISON UNDERGROUND-TUBE SYSTEM.

**29.** The **Edison underground-tube system** differs from the conduits previously described in that the conductors are placed in iron tubes that are buried in the ground. The conductors are, therefore, not removable. This arrangement has been used extensively by illuminating and power companies in the larger cities. The conductors themselves are usually in the shape of round copper rods; the main tubes are designed for use on the three-wire system and are, therefore, provided with three rods, as shown in the section in Fig. 30. Each rod is wound with an open spiral of rope that serves to keep the rods separated in case the insulating

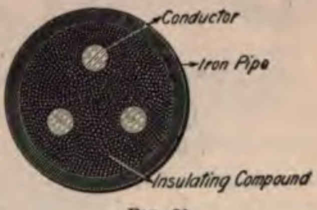

FIG. 30.

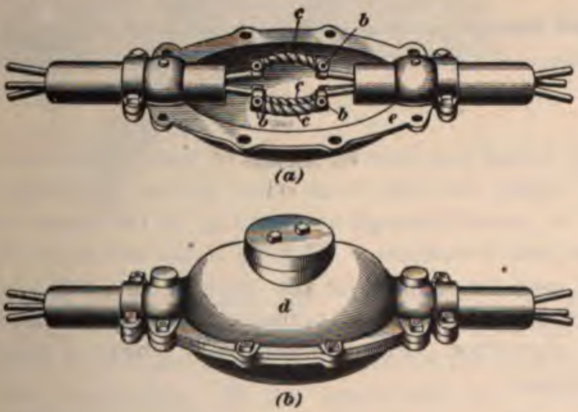

FIG. 31.

material in the tubes should become soft. After the rods have been provided with the rope spiral, they are bound together by means of a wrapping of rope and inserted in the iron pipe, the rods projecting for a short distance at each end. The whole tube is then filled with an insulating compound that becomes hard when cold. The tubes are made in 20-foot lengths and are laid in the ground about 30 inches below the surface of the pavement. They are joined together by means of the coupling boxes shown in Fig. 31 (*a*) and (*b*). Fig. 31 (*a*) shows the lower half of the box only, with the main tubes entering each end. The conductors are connected together by means of short, flexible, copper cables *c*, *c*, *c*, provided with lugs *b*, *b*, that fit over the rods and are soldered in place. A cover *d* similar to the lower half *e* is then placed in position and the two securely bolted together by means of flange bolts, as shown in (*b*). After this has been done, melted insulating compound is poured through an opening in the upper casting and the joint is complete. Fig. 32 shows two styles of connectors used for connecting the ends of the rods; (*a*) is a stranded copper cable with terminals and (*b*) is a laminated copper connector. Fig. 33 indicates a length of pipe with its couplings.

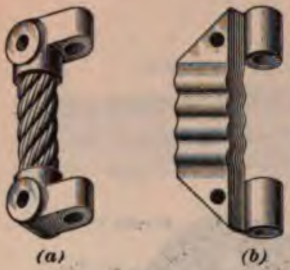

FIG. 32.

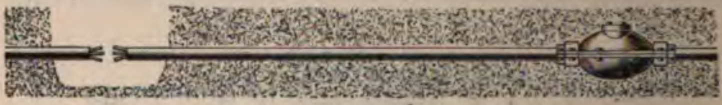

FIG. 33.

**30.** Where branches are taken off the mains, **T** coupling boxes are used, as indicated in Fig. 34. This box, also, is filled with insulating compound that soon becomes hard and prevents the flexible connections from coming in contact with one another. At the centers of distribution (usually a street intersection) junction boxes are provided. These correspond to the manholes of the conduit system. The main supply wires, or feeders, run from the station to these junction boxes, whence the mains are run to the various districts where light or power is supplied. Fig. 35 shows one of these junction boxes. The tubes enter at the lower part of the cast-iron box, and the mains are connected to the feeders through fuses that bridge over between the rings shown at the top. These fuses must be proportioned according to the size of the conductor in the tube to which they are connected. If the conductors are overloaded, they will heat and destroy the insulation. The allowable carrying capacities of underground tubes and cables have been made the subject of a large number of tests by the manufacturers, who furnish tables giving the limit to which

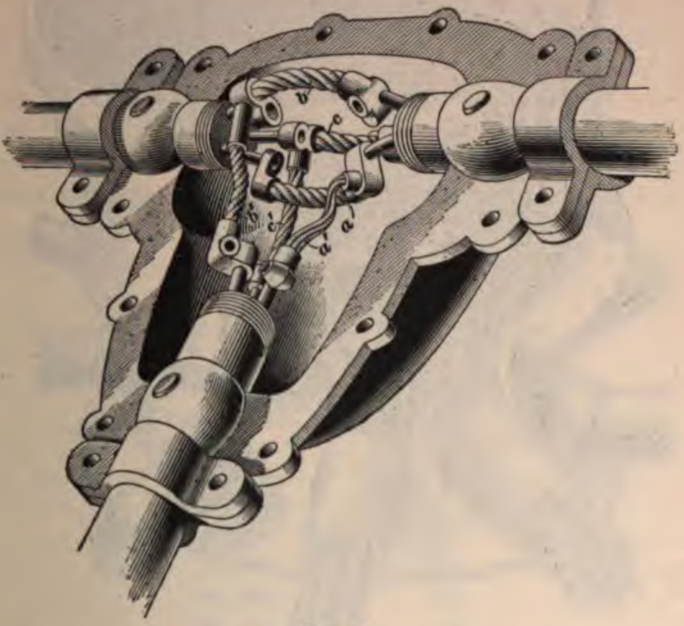

FIG. 34.

their cables or tubes may be loaded with safety. The junction box shown in Fig. 35 is made water-tight by clamping down the cover by means of the studs *b*, *b* and the whole is then covered with a cast-iron plate resting in the groove *c* and coming flush with the street surface.

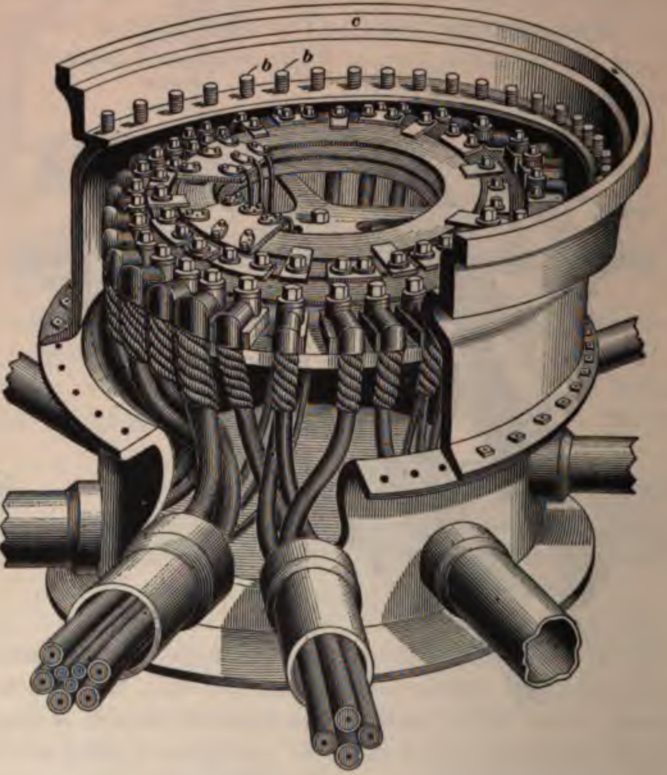

FIG. 35.

**31.** The underground tubes and fittings are rather expensive, but they are comparatively cheap to install, as all that is necessary is to dig a shallow trench and lay the tubes in the ground. This system has the disadvantage that if any trouble occurs it is somewhat awkward to get at it, as the conductors cannot be pulled out as in a conduit system. When trouble occurs, the usual method of procedure is to dig a hole at one of the couplings and separate the ends. By making a few breaks in this way at different points, the section in which the ground or short circuit is present can soon be located and the defective length of tube removed.

**32.** The Edison tube system is not now used as largely as it once was for the main distributing lines or feeders. The present practice is to carry the main conductors from the station to the various distributing points in ducts, so that they may be drawn out if necessary. The tube system is, however, well adapted for the distributing mains, and is largely used for this purpose, because it allows service connections to be made easily and cheaply. Table I gives the cross-section of the rods used in the standard

### TABLE I.

### CARRYING CAPACITY OF UNDERGROUND TUBES.

| Size of Each Conductor in Circular Mils. | Maximum Current in Each of Two Conductors. |
|---|---|
| 41,000 | 100 |
| 80,000 | 200 |
| 100,000 | 235 |
| 120,000 | 260 |
| 150,000 | 295 |
| 200,000 | 350 |
| 250,000 | 400 |
| 300,000 | 450 |
| 350,000 | 495 |
| 400,000 | 540 |
| 450,000 | 580 |
| 500,000 | 620 |

tubes that are now used for distributing mains. Each tube has three conductors of the same size and the table shows the allowable current when two of the conductors are loaded. If the system is balanced, the third wire will carry but a small current.

## TESTS.

**33.** In testing lines or apparatus, it is frequently necessary to make rough tests that will show whether or not circuits are continuous, broken, crossed, grounded, or properly insulated. These tests do not require accurate measurements, they being merely for the purpose of determining the existence of a faulty condition.

**34. Magneto Testing Set.**—The most common, and probably, all things considered, the most useful, form of testing instrument for rough testing is that consisting of a magneto generator and bell mounted compactly in a box provided with a strap for convenience in carrying.

### TESTING LINES FOR FAULTS.

**35.** Faults on a line may be of two kinds: the line may be entirely broken, or it may be unbroken but in contact with some other conductor or with the ground. The former fault is termed a **break**; the latter a **cross** or **ground**. A break may be of such a nature as to leave the ends of the conductor entirely insulated, or the wire may fall so as to form a cross or ground. A cross or ground may be of such low resistance as to form a short circuit or it may possess high resistance, thus forming what is called a **leak**. There are a number of different methods used for locating faults, and as those most suitable depend to a considerable extent on the kind of work for which the lines are used, most of the points relating to testing will be left until the different subjects with which they are connected are considered.

**36. Continuity Tests.**—In testing wires for continuity, the terminals of the magneto set should be connected to the terminals of the wire and the generator operated. A ringing of the bell will usually indicate that the circuit is continuous. This is a sure test on short lines, but should be used with caution on long lines and in cables, because it may be that the electrostatic capacity of the line wires themselves will be sufficient to allow enough current to flow through the ringer to operate it, even though the line, or lines, is open at some distant point.

**37. Testing for Crosses or Grounds.**—In testing a line for crosses or grounds, one terminal of the magneto set should be connected to the line under test, both ends of which are insulated from the ground and from other conductors. The other terminal of the magneto set should be connected successively with the earth and with any other conductors between which and the wire under test a cross is suspected. A ringing of the bell will, under these conditions, indicate that a cross exists between the wire under test and the ground or the other wires, as the case may be, and the strength with which the bell rings, and also the pull of the generator in turning, will indicate, in some measure, the extent of this cross.

**38.** Here, however, as in the case of continuity tests, the ringing of the bell is not a sure indication that a cross exists if the line under test is a very long one. The insulation may be perfect and yet permit a sufficient current to pass to and from the line through the bell to cause it to ring, these currents, of course, being due to the static capacity of the line itself. In testing very long lines or comparatively short lines of cable, the magneto set must be used with caution and intelligence on account of the capacity effects referred to. For short circuits in local testing, however, the results may be relied upon as being accurate.

Magneto testing sets are commonly wound in such manner that the generator will ring its own bell through a resistance of about 25,000 ohms. They may, however, be arranged to ring only through 10,000 ohms, or where especially desired, through from 50,000 to 75,000 ohms. The first figure mentioned—25,000 ohms—is probably the one best adapted for all-round testing work.

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### CURRENT DETECTOR GALVANOMETER.

**39.** In order to test for grounds, crosses, or open circuits on long lines or on cables, without the liability to error that is likely to arise in testing with a magneto set, a cheap form of galvanometer for detecting currents, called a **detector galvanometer,** may be used. In testing for grounds or crosses, the galvanometer should be connected in series with several cells of battery and one terminal of the circuit applied to the wire under test, it being carefully insulated at both ends from the earth and from other wires, while the other terminal of the galvanometer and batteries should be connected successively to the ground and to adjoining wires. A sudden deflection of the galvanometer needle will take place whenever the circuit is first closed, this being due to the rush of current into the wire that is necessary to charge it. If the insulation is good, the needle of the galvanometer will soon return to zero; but if a leak exists from a line to the ground or the other wire with which it is being tested, the galvanometer needle will remain permanently deflected.

In testing for continuity, the distant end of the line should be grounded or connected with another wire that is known to be good, and the galvanometer and battery applied, either between the wire under test and the ground or the wire under test and the good wire. In this case, a permanent deflection of the galvanometer needle will denote that the wire is continuous, while if the needle returns to zero it is an indication of a broken wire.

**40. Test for Insulation Resistance.**—One thing that it is important to know about lines is the state of their insulation. In order to determine this, measurements of the insulation resistance between the line and ground must be made, and if this resistance is found to be dangerously low, the trouble should at once be looked up and remedied. One of the most convenient methods for measuring insulation resistance is by means of a good high-resistance voltmeter. The voltmeter is much easier to handle than a reflecting galvanometer, and if the resistance of the voltmeter is known, insulation resistance measurements may be made with very little trouble. Suppose in Fig. 36 we wish to measure the insulation resistance of the line *A A*. The voltmeter is first connected across the lines at *V* in the usual manner and the voltage of the dynamo *D* obtained. Call this reading $V$. As soon as possible after taking the reading $V$, the voltmeter is connected between the line *B B* and the ground, as shown at $V_1$, and a reading $V_1$ obtained. In this case all the current that goes through the voltmeter passes from *f* to $E_2$ and thence back through the ground *E* and the insulation of the line to *l*. It is evident that if the insulation resistance of the line *A A* is very high, very little current will flow through the voltmeter, and a small deflection will be the result. If the resistance *r* of the voltmeter is known, then the insulation resistance of the line will be

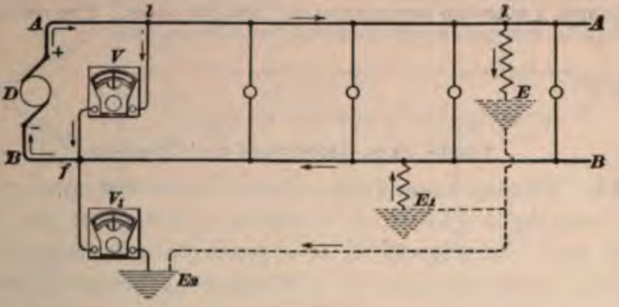

FIG. 36.

$$R = \frac{(V - V_1)\,r}{V_1}, \qquad \textbf{(1.)}$$

provided no ground exists on the dynamo *D*.

EXAM he insulation resistance of an electric-light main was
tested ns of a Weston voltmeter having a resistance of
00 ohms. Vhen connected across the lines, the voltmeter gave a
ling of 11 olts. When one line was connected to ground through
the voltmet he reading was only 4 volts. What was the insulation
other line?

SOLUTION.— We have by formula 1,

$$R = \frac{(110 - 4)\ 18{,}000}{4}$$

$$= \frac{106 \times 18{,}000}{4}$$

$$= 477{,}000 \text{ ohms.} \quad \text{Ans.}$$

resistance o nes is usually expressed in
ual to 1,0 00 ohms. The resistance of
refore be 7 megohm.

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## TESTS FOR GROUNDS OR CROSSES.

**41. Varley Loop Test.**—One of the commonest methods locating a ground or cross is y means of the Varley p test. In Fig. 37, *G* is a sen tive galvanometer connected across the arms of a Wheatstone bridge in the ordinary manner; *A B* and *A C* are the ratio arms and *C D* the

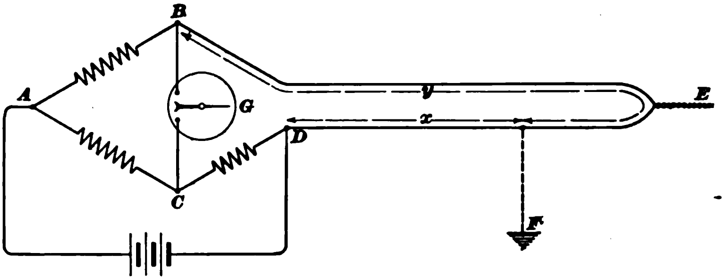

FIG. 37.

rheostat or balance arm of the bridge. *D E* is the faulty line and *F* the location of the fault. The two lines should be connected together at *E* and the ends of the loop *B E D*, so formed, connected across the terminals of the bridge as the unknown resistance. Call $y$ the resistance of the loop from $B$ to $F$ and $x$ the resistance from $D$ to $F$. With the battery connected between $A$ and $D$, as in the ordinary method of using the Wheatstone bridge, balance the bridge. This will give, by working out the unknown resistance in the usual manner, a resistance $R$ equal to the sum of the resistances of the two wires forming the loop; that is,

$$R = y + x.$$

Or, the resistance $R$ of the whole loop may be calculated, because the length and size of the line wire are known.

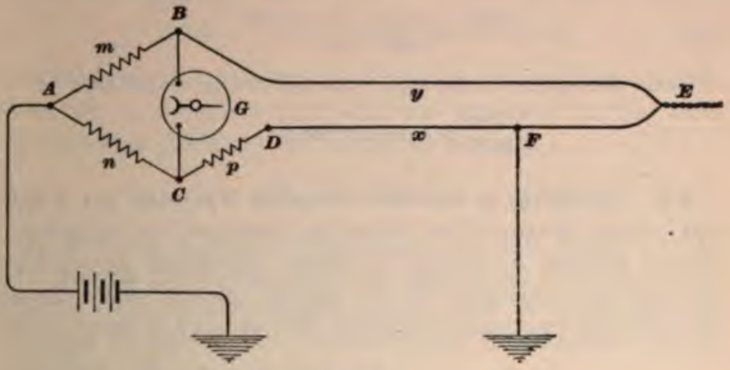

FIG. 38.

Now disconnect the battery from $D$ and connect it to the ground, as shown in Fig. 38. Then balance the bridge again, and the resistance $x$ may be obtained by means of the following formula:

$$x = \frac{nR - mp}{m + n}, \qquad (2.)$$

in which $m$, $n$, and $p$ are the values of the resistances in the arms $AB$, $AC$, and $CD$. After obtaining the resistance $x$ from $D$ to the fault $F$ along the line $DE$ by means of formula **2,** the distance (in feet or miles) from the testing end $D$ to the fault $F$ may be obtained by dividing this resistance $x$ by the resistance of a unit length (a foot or a mile, as the case may be) of the line wire $D E$. The result obtained by this test is independent of the resistance at the fault between the line and the ground.

EXAMPLE.—A ground occurred on a conductor of a cable 10,000 feet long composed of three No. 10 wires. One good wire was used to complete the loop. On testing with one end of the battery grounded as in Fig. 38, the bridge was balanced with the following resistances: $m = 10$ ohms, $n = 1{,}000$ ohms, $p = 1{,}642$ ohms. Where was the ground, the resistance per 1,000 feet of the conductor being .9972 ohm ?

SOLUTION.—The length of the loop formed by joining the two wires of the cable at the distant end will be 20,000 feet;

hence, $R = 20 \times .9972 = 19.944,$

and $x = \dfrac{1{,}000 \times 19.944 - 10 \times 1{,}642}{1{,}000 + 10} = 3.4891.$

Hence the distance of the fault from the testing station must be

$$\frac{3.4891}{.9972} \times 1{,}000 = 3{,}498.9 \text{ ft. Ans.}$$

**42. Locating a Partial Ground Without an Available Good Wire.**—The following method for locating a partial ground or escape is rather unreliable in practice, because the resistance of the partial ground may change between the two measurements, and so give a more or less incorrect result. However, it is about the only way where there is no available good wire and when the tests must be made from one end only. The normal resistance of the line must be known from some previous measurement, unless it can be calculated from the length and size of the

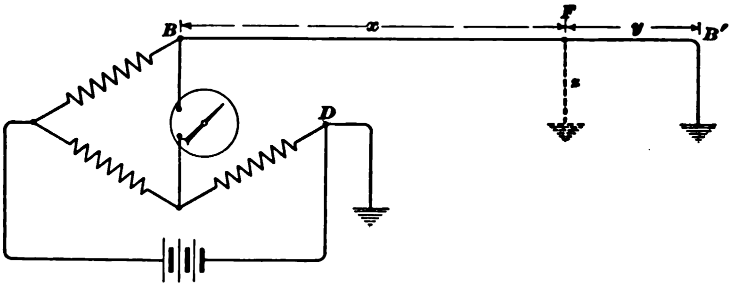

FIG. 39.

wire. Let this resistance be $a$; then measure the resistance of the line $B\,B'$, with the distant end $B'$ grounded as shown in Fig. 39, and call this $c$. Also measure the resistance with the distant end open, as in Fig. 40, and call this $b$ ohms. Then the resistance $x$ to the partial ground from the testing station is given by the following formula:

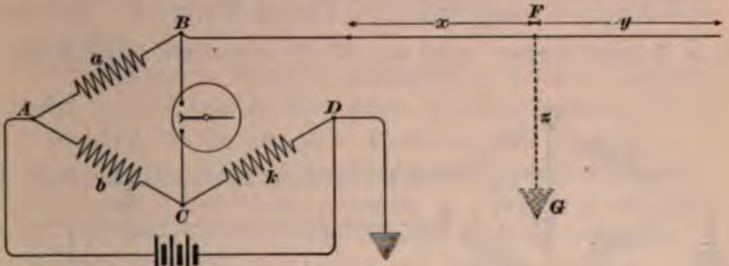

FIG. 40.

$$x = c - \sqrt{(b - c)\,(a - c)}. \qquad \textbf{(3.)}$$

By dividing $x$ by the resistance per unit length of the wire, known from some previous measurements or by a calculation from its size, length, and a table of resistances for the kind of wire under consideration, the distance to the grounded point may be obtained.

**43. To Locate a Cross by the Varley Loop Method.**—First insulate the distant ends of the two crossed wires. Then connect as shown in Fig. 41 and measure the resistance from $D$ to $B$ through the cross $F$. Let the

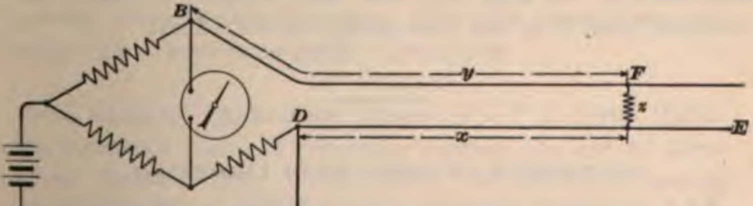

FIG. 41.

resistance of the cross be $z$ ohms and the resistance found by balancing the bridge be $R$ ohms.

Then, $$R = x + y + z. \quad (1)$$

Now ground either wire, say $D\,E$, anywhere beyond the cross, and connect as shown in Fig. 42. When the bridge is again balanced, we have

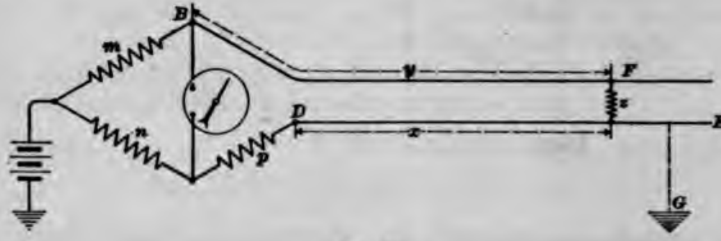

FIG. 42.

$$\frac{m}{n} = \frac{y + z}{p + x}. \quad (2)$$

From equations (1) and (2), we get

$$x = \frac{n\,R - m\,p}{m + n}.$$

This is the same as formula **2.** By dividing $x$ by the resistance of the wire $D\,E$ per unit length, we have the distance from $D$ to the fault along the wire $D\,E$.

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### PROTECTION OF LINES FROM LIGHTNING.

**44.** Overhead lines are always liable to accumulate a certain charge of static electricity even if they are not actually struck by lightning. Long transmission lines should be well protected against lightning, as they frequently run through exposed and mountainous country. If these high-pressure discharges travel along the line and get into the dynamos at the power station, they are almost sure to puncture the insulation of the machines and result in a burn-out. To guard against this, lightning arresters should be provided.

It was formerly thought sufficient to place a lightning arrester on each line at the station, trusting to these to lead any discharge to the ground. However, this was found to be an unsafe practice. It is now generally admitted that the safest plan is to distribute a number of arresters at intervals along the line, so that any charge that may happen to accumulate will be led to ground before it reaches the station. There are a large number of different types of lightning arresters in use that accomplish their purpose more or less perfectly. They offer a great deal of protection if properly installed; but, as is well known, lightning is very erratic in its behavior and often does damage in spite of the lightning arresters. This is no reason, however, why every line should not be equipped with them at intervals of about every half mile at least. What is given here is intended to apply to lightning arresters in a general way, and the description of special types will be taken up later in connection with the special lines of work to which they are adapted. The arresters for any given line must be selected with reference to the kind of circuit on which they are to be used, and descriptions of some of the more important types will be given in connection with the subjects of *Electric Lighting* and *Electric Railways*. For the present we will confine our attention to general principles.

**45. Simple Lightning Arrester.**—The term **lightning arrester** does not correctly express the use of these devices, because they do not arrest the discharge coming in over the line; they merely divert the charge by providing a path to the ground that the lightning will take in preference to passing into the dynamo and making a path for itself to the ground by puncturing the insulation of the machine.

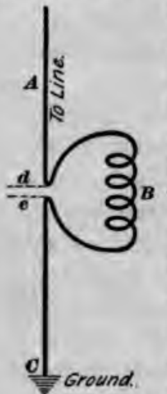

FIG. 43.

In order to understand the action of the lightning arrester, it must be remembered that a lightning discharge is oscillatory in character, i. e., it is rapidly changing in a manner somewhat similar to an alternating current, the frequency of which is exceedingly high. On account of its rapidly changing character, lightning will not pass through an inductive path if there is a non-inductive path provided for it. The armature of a dynamo always possesses a certain amount of self-induction, and a comparatively small amount of self-induction will offer a very high resistance to a lightning discharge. Every coil of wire has some self-induction, and a lightning discharge will jump across an air gap that has no self-induction before it will pass through a coil, even if the ohmic resistance of the coil is very low. Suppose we have a short air gap *d e*, Fig. 43, and a coil *B* arranged as shown. If terminal *C* is connected to the ground and a discharge comes in over the line *A*, it will jump the gap *d e* rather than pass through the coil *B*, even though this coil is made of heavy wire and contains but few turns. The simplest form of lightning arrester is that shown in Fig. 44. A pair of plates *1*, *2* are connected one to each line and are separated by a small gap *g* from

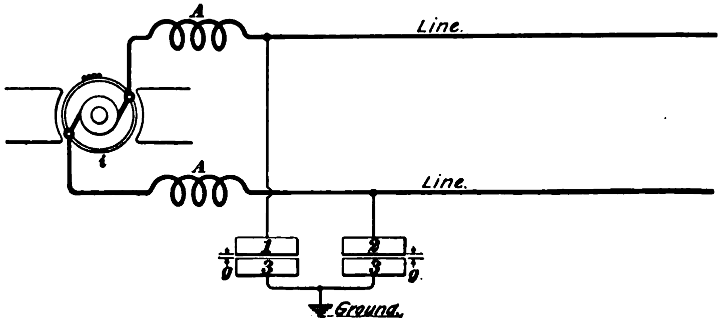

FIG. 44.

two other plates *3*, *3* that are connected to the ground. The gap in the arrester should be more easily jumped across by the discharge than the thinnest insulation *i* on the dynamo, otherwise the discharge will jump through the insulation to the ground instead of jumping across the air gap. The air gap must, of course, be long enough that the pressure generated by the dynamo itself will not be able to jump across it. For pressures up to 500 volts a gap of $\frac{1}{32}$ inch should be sufficient, and a gap of this length offers considerably less resistance to the discharge than the insulation on the dynamo.

**46. Reactance, or Kicking, Coils.**—In order to make more certain that the discharge will pass through the arrester, **kicking coils,** or **reactance coils,** are often inserted between the arrester and the dynamo. A kicking coil, or reactance coil, is a coil of wire consisting of a few turns inserted in the circuit between the arrester and the apparatus to be protected, as shown at *A A*, Fig. 44. These coils have a certain amount of self-induction, and the consequence is that when a discharge comes in over the line, they offer a high resistance to its passing into the dynamos. They choke back the discharge and force it to pass to the ground by jumping the air gap. Fig. 45 shows a typical kicking coil.

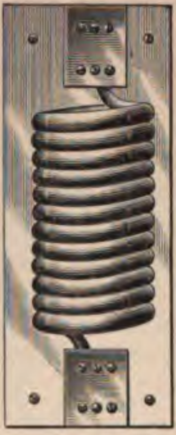

FIG. 45.

**47. Suppression of Arcing.**—The simple arrangement of air gaps shown in Fig. 44 will hardly work on electric-light and power circuits for the following reason: If a discharge comes in over both the lines at once, as is quite likely to happen, because the lines usually run side by side, an arc will be formed across both the gaps, and current from the dynamo will follow the arc. The result will then be practically a short circuit on the dynamo, and such a large current will flow that the plates or contact points of the arrester will be destroyed. It is necessary, then, to have in addition to the air gap some means for suppressing or blowing out the arc as soon as it is formed. It is also necessary that as soon as the discharge has passed, the arrester will be in condition for the next discharge. Generally speaking, the arc from a continuous-current machine is not as easily extinguished as that from an alternator; probably because every time the current passes through its zero value it loses some of its ability to hold the arc. A large number of different types of arresters have been brought out. In some cases, the arc is broken by being drawn out until it can be no longer maintained; in others, the air gap is so placed that it will be surrounded by a magnetic field, so that when the arc is formed it is forced across the field in just the same way that a wire carrying a current moves across the magnetic field in a motor. The result is that the arc is stretched out until it is broken. The magnet blows out the arc almost instantaneously. Another method for suppressing the arc following the discharge is to make it occur in a confined space so that it will be smothered out. Still another method is to make the cylinder or plates between which the arc jumps of a so-called non-arcing metal. The vapor of this metal offers a high resistance to the discharge, and, hence, the dynamo is unable to maintain the arc. Some arresters will work on either direct or alternating current; but, generally speaking, the arrester has to be selected with reference to the voltage of the circuit on which it is to be used and also with reference to the kind of current, i. e., direct or alternating.

**48. Ground Connections for Lightning Arresters.**—As stated above, it is best to be on the safe side and distribute lightning arresters along the line as well as placing them in the station. These arresters will, however, be of little or no use if good ground connections are not provided for them. The following methods of making ground connections are recommended by the Westinghouse Company.

**49.** The method of making the ground connection for a line or pole lightning arrester is shown in Fig. 46. A galvanized-iron pipe is driven well into the ground and the top of it surrounded by coke, which retains moisture; the wire is run down the pole and connected to the top of the pipe as indicated. The wire is sometimes encased in galvanized-iron pipe for about 6 feet from the base of the pole. If this is done, it is well to solder the ground wire to this pipe at *a*. When a number of arresters are installed on the lines entering the station, special care should be taken in making the ground connection, otherwise the whole lightning-arrester installation may be practically useless. The following method of making the ground connection is recommended: A hole 6 feet square is dug 5 or 6 feet deep in a location as near the arresters as possible, preferably directly under them. The bottom of this hole is then covered with charcoal or coke (crushed to about pea size) to a depth of about 2 feet. On top of this is laid a tinned, copper sheet, about 5 ft. × 5 ft., with the ground wire (about No. 0 B. & S.) soldered completely across it. The plate is then covered with a 2-foot layer of coke or charcoal and the remainder of the hole filled with earth, running

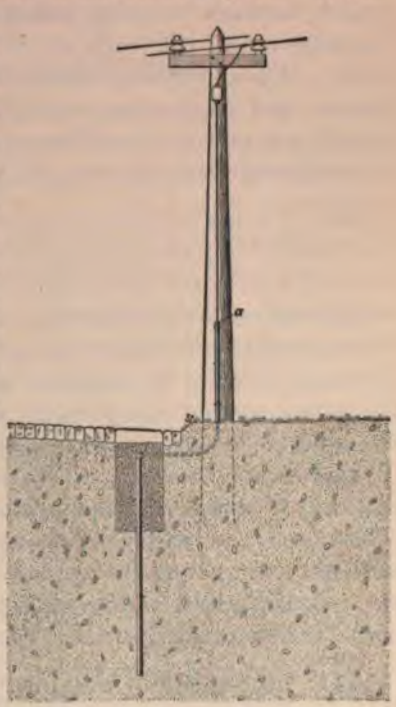

FIG. 46.

water being used to settle it. This will give a good ground, if made in good, rich soil. It will not give a good ground in rock, sand, or gravel. Sometimes grounds are made by putting the ground plate in a running stream. This, however, does not give as good a ground as is commonly supposed, because running water is not a particularly good conductor and the beds of streams very often consist of rock. When lightning arresters are installed, all wires leading to and from them should be as straight as possible. Bends act more or less like a choke coil and tend to keep the discharge from passing off by way of the arrester.

**50.** For long-distance, high-tension lines, another method for protection from lightning has been adopted in some cases. Barbed wire is run along the tops of the poles and is thoroughly grounded at intervals. This wire collects the static charges and leads them to the ground. On these very high-pressure lines, it is necessary to use a number of air gaps in series, so that the pressure of the line will not of itself be able to set up a current to the ground. This usually means that either a special form of arrester with a large number of gaps in series, or a number of regular arresters connected in series, must be used. The use of the barbed wire does away with the need of line arresters. It is claimed that it has given very good results in some cases, while in others the lightning arresters have been preferred.

**51. Lightning Arresters on Underground Lines.**—It would hardly seem necessary to equip lines that are wholly underground with lightning arresters. While it is true that such lines are not at all in danger from ordinary lightning discharges, nevertheless it has been found that when underground cables are used in connection with high-tension transmission systems, static charges of electricity gradually accumulate; and if these charges are not allowed to pass off to the ground, they may puncture the insulation of the cables. The lines are, therefore, very often protected by lightning arresters or static dischargers that are similar in construction to a lightning arrester, to allow the escape of these static charges to earth. For example, the underground distributing system of the Metropolitan Street Railway Company, of New York, is fully equipped with lightning arresters, although no part of the system is above ground.

## STORAGE BATTERIES.

**52.** The *storage battery*, or *accumulator*, is now so largely used in connection with electric-transmission plants of various kinds that a general description of its action will be given here. Its use in connection with special lines of work will be considered more fully when the subjects of *Electric Lighting* and *Electric Railways* are taken up.

**53.** **Accumulators, storage batteries,** or **secondary batteries** are those in which a chemical change is brought about by sending current through the cell from some outside source, the chemical compounds so formed being capable of delivering electrical energy when changing back to their former state when the cell is discharged. The storage battery does not, therefore, store up electricity; it is simply a cell, in which the changes brought about by the charging current put the cell in a position to deliver electricity in much the same way as any ordinary primary battery. A large number of different types of storage cell have been devised, but the only kind that has come into extensive use is the lead accumulator. In this cell, lead in some form is used for both the positive and negative plates, and the solution, or electrolyte, is a mixture of sulphuric acid and water.

**54.** Fig. 47 shows a typical storage cell made by the Electric Storage Battery Company and known as the **chloride accumulator.** These cells can be obtained in a variety of sizes from the small type, having only three plates (two negative and one positive), to the very large cells used in connection with central stations and substations. The cell shown is mounted in a glass jar. For very large cells wooden tanks lined with lead are used, while for portable batteries the jars are made of hard rubber.

**55. Positive and Negative Plates.**—In Fig. 47, *a*, *a*, *a* are the positive plates and *b*, *b* the negative plates. Before going further, it may be well to point out just what is meant by the positive and negative plates of a storage battery. So far as appearance goes, the two plates may look very much alike, especially when the cell is discharged, but the **positive** plate is always the one at which the current flows *out* when the cell is discharging and *in* when it is charging. In charging a battery, one must always be sure to get the positive pole of the battery connected to the *positive* pole of the dynamo, so that the *charging* current will flow *in* at the positive pole. When the charging current is discontinued and the cell allowed to supply current to a circuit, the *discharging* current will flow *out* from the positive pole of the cell. The positive plates are, or should be, marked, so that there will be no danger of incorrectly connecting the cells. When a pole indicator is not at hand, the polarity may always be found by connecting a wire to each pole and dipping the ends into a dilute solution of sulphuric acid. The wire from which the greater number of bubbles is given is connected to the negative pole. When connecting cells in series, care should be taken to see that the positive pole of one cell is connected to the negative pole of the next. Any person that has worked around storage cells for any length of time can tell the positive plates from the negative by their dark-brown color.

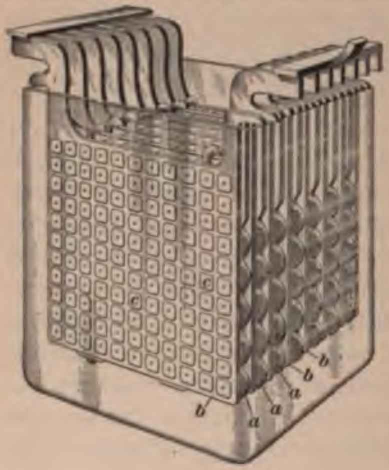

FIG. 47.

**56.** The complete chemical reactions that take place in a storage battery are complicated and many of them are not as yet well understood. When the cell is charged, the principal action is the formation of lead peroxide on the positive plate and spongy lead at the negative. Lead peroxide is a chemical compound consisting of 1 atom of lead and 2 atoms of oxygen; its chemical formula is $PbO_2$. This lead peroxide gives the positive plates the dark-brown color that they have when the cells are fully charged. When the cell is discharged, the lead peroxide gradually changes to lead sulphate and the metallic lead on the negative plate is also changed to lead sulphate. Lead sulphate $PbSO_4$ is formed by the action of the sulphuric acid in the electrolyte of the cell on the spongy lead. These chemical changes are repeated over and over as the cell is charged and discharged.

**57.** In Fig. 47, the plugs *c*, *c* seen in the negative plate are the portions of the plate that take part in the action of the cell. The framework, or surrounding grid, serves to hold the active material in place. When the cell is discharged, these plugs are reduced to spongy lead. In the positive plate, the active material is placed in round holes, each of which contains a plug made of corrugated lead ribbon curled into spiral form. This lead ribbon, after being fixed in place, is converted into lead peroxide, and thus forms the active material of the positive plate.

**58.** In some batteries, the active material is formed by means of chemical action on the plate itself and is not held in holes or pasted on the supporting grid. This was the method adopted by Planté, the originator of the storage battery. The pasted plate was brought out later by Faure. The Willard plate,

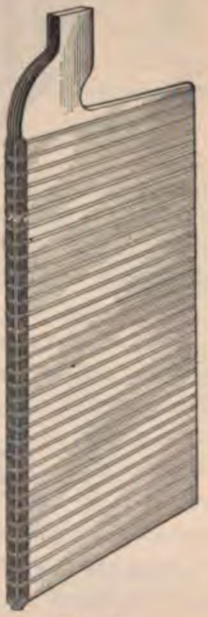

FIG. 48.

Fig. 48, is an example of one where the active material is formed on the plate itself. It consists of a lead plate provided with deep, narrow grooves, as shown. These grooves incline upwards and make the plate present a very large surface to the action of the electrolyte. The lead peroxide is formed on these plates by means of chemical action, and, as the grooves incline upwards, there is little chance for any of the material to become detached and fall out. Fig. 49 shows a cell consisting of a number of these plates mounted in a sealed hard-rubber jar so that the cell will be portable. Cells of this kind are designed for use on electric vehicles. The plates are separated by a perforated rubber plate that precludes any possibility of their coming in contact with one another.

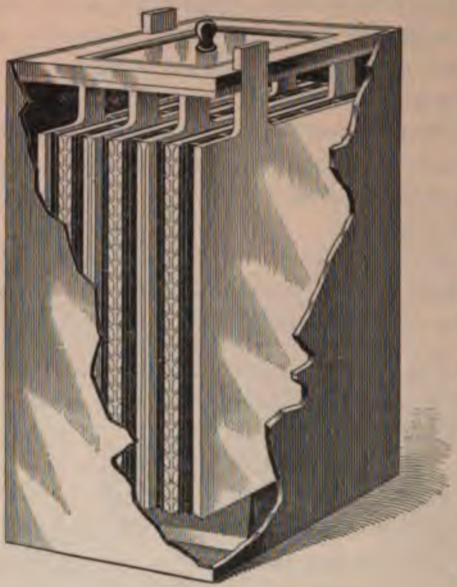

FIG. 49.

**59. Rating of Storage Cells.**—The capacity of a storage cell is generally given as so many *ampere-hours*. Thus, a cell that can deliver normally a current of 10 amperes for a period of 8 hours will have a capacity of 80 ampere-hours. If a cell is discharged at a rate higher than that for which it is designed, its output will be diminished. For example, in the above case, if the cell were made to deliver 16 amperes instead of 10, it would not keep up its discharge for 5 hours so as to give its total capacity of 80 ampere-hours. It does not pay in any event to take a larger current from a cell than that for which it is designed, as it only results in a low efficiency and is liable to buckle or disintegrate the plates. The ampere-hour output of a cell is obtained by multiplying the average current in amperes by the time in hours during which the current is delivered.

The capacity of a cell in *watt-hours* is obtained by multiplying the average number of watts delivered by the number of hours. The *efficiency* of a cell is the ratio of the watt-hours delivered to the watt-hours supplied. This gives the true efficiency of the cell, although the ampere-hour efficiency, i. e., the ratio of the ampere-hours delivered to the ampere-hours supplied, is often taken as the efficiency of the cell. This would be correct if the voltage at charging were the same as when discharging, but such is not the case. The ampere-hour efficiency may be as high as 95 per cent., while the watt-hour efficiency is usually from 75 to 85 per cent. and represents the true efficiency of the battery. Small cells have a capacity of about 3 ampere-hours per pound of total weight, while large central-station cells may run as high as 6 to 7 ampere-hours per pound. An ordinary battery will weigh anywhere from 120 to 180 pounds per horsepower-hour capacity.

**60. Voltage of Storage Cells.**—The voltage required for charging a storage cell varies from 2 to 2.5 volts per cell. The voltage required gradually increases as the cell becomes charged. The voltage obtained at the discharge is from 2.2 to 1.8 volts, the pressure falling off as the cells become discharged. The difference between the voltage required to charge a storage battery and that obtained at the discharge is due largely to the internal resistance of the cells; thus it will now be readily seen why the watt-hour efficiency may be considerably less than the ampere-hour efficiency.

If we wish to charge 50 cells in series, the dynamo must be capable of furnishing $50 \times 2 = 100$ volts at the beginning of the charging, and this voltage must be increased to $50 \times 2.5 = 125$ volts as the cells become fully charged.

This is usually done by cutting resistance out of the field of the dynamo as the charging process proceeds. If only 20 cells, say, are to be charged, we will require from 40 to 50 volts; and if they are to be charged from a 100-volt dynamo, enough resistance must be inserted in series with them to take up the extra 60 to 50 volts. Hence, if the charging current were, say, 5 amperes, there should be at least $\frac{60}{5} = 12$ ohms resistance in series. If this were not used, the charging current would be excessive and the cells would be injured. Cells should not be discharged to such an extent that their pressure falls below 1.8 volts.

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## CARE AND OPERATION OF STORAGE CELLS.

**61. Installation.**—Cells should be installed in a room where the ventilation is good and where they may be easily inspected. They are generally mounted on a heavy framework that has been painted with acid-proof paint, and if the space is limited, are arranged in two or more tiers. Storage cells are heavy and the framework should be very substantial. It is necessary to watch the cells to see if any of the plates get into bad condition, also to test the condition of the electrolyte and renew it when necessary. It is important, therefore, that the cells shall be so arranged that the attendant can readily move around among them. The cells should be well insulated, otherwise the acid film that is sure to accumulate sooner or later may result in considerable leakage. It is a common practice to set each cell in a shallow tray about half full of sand and then support this tray on insulators. Fig. 50 shows an oil insulator that has been largely used for this purpose. It is made in halves and oil is placed in the lower half, as shown. The surface of the oil offers a high resistance to any leakage that may tend to

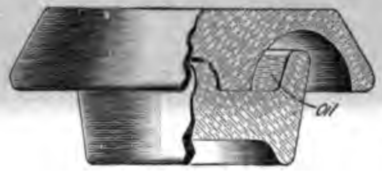

FIG. 50.

occur between the cell and the supporting framework. The cells are nearly always joined to each other by burning, or fusing, the lead terminals together. Soldering is not, as a rule, satisfactory or permanent. Mechanical clamping connections are not generally favored, for they do not give as low a resistance as the burnt connection, and if they are not made wholly of lead they soon become corroded.

**62. The Electrolyte.**—As already stated, the electrolyte consists of a mixture of sulphuric acid and water. There is a difference of opinion as to what the strength of the mixture should be, and makers of batteries send instructions with their cells as to the strength that they consider essential to secure the best results with their particular make of cell. The proper strength of the electrolyte is determined by means of a hydrometer.

Fig. 51 shows a storage-battery hydrometer. It consists of a sealed tube, or stem, provided with a bulb that is partially filled with shot or mercury. If placed in water, such a hydrometer will sink; but if acid is added, the solution becomes heavier, or more dense, and the hydrometer will float until its stem projects vertically out of the mixture. When the specified mark on the stem comes even with the surface, it shows that the proper density of mixture has been attained. The electrolyte in the cells should be tested from time to time to see that the density is correct. If it is found too high, some of the solution should be drawn off and more water added. The electrolyte will evaporate to some extent, and this loss should be made good by the addition of water. The density increases to some extent as the cell becomes charged. The usual density of the solution should be about 1.2, or 1,200 on some hydrometer

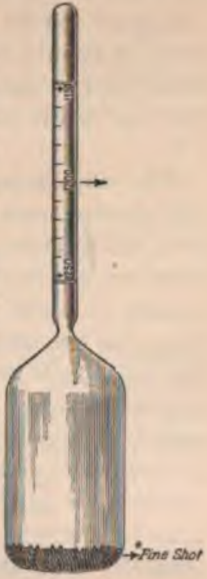

FIG. 51.

scales, though some manufacturers use a higher density than this. This means that the weight of the solution, per unit volume, is 1.2 times that of water. With ordinary commercial acid this density requires about 3 parts, by volume, of water to 1 part of acid.

When mixing the electrolyte, pure acid and water should be used; the water used for the electrolyte should be distilled. The acid evaporates very little, though some of it may be lost in the form of spray thrown off. The evaporation is nearly all water; hence, it is not often necessary to add acid to the cells. The electrolyte should be cold before it is placed in the cells, and they should be charged as soon as it is placed in them. They should not, at the most, be allowed to stand for more than 2 hours before being charged. It may be well to mention here that when sulphuric acid is to be mixed with water, *the acid should be poured slowly into the water.* If the water is poured into the acid, the sudden evolution of heat is apt to throw the mixture into the operator's face. The satisfactory operation of a battery depends to a great extent on the correct strength of the electrolyte, hence it should be carefully watched. The cells should be kept filled so that the electrolyte will always be slightly over the tops of the plates.

**63. Charging.**—Fig. 52 shows about the simplest possible arrangement of connections for charging a storage battery, all appliances that are not absolutely necessary having been left out in order to avoid confusion. *A* is a dynamo, usually either of the shunt-wound or compound-wound variety; *f* is the rheostat in its shunt field, by means of which the voltage of the machine may be varied through a considerable range; *V* is a voltmeter connected to the voltmeter switch *S*, which is so arranged that the voltmeter may be connected to either the battery *C* or the dynamo *A*; *E* is a double-pole knife switch, by means of which the battery may be thrown in connection with the dynamo; *F* is an ammeter that shows the amount of the charging current. The ammeters used with storage batteries are often made with their zero point in the middle of the scale. When the battery is charging, the needle is deflected to one side of the zero mark; when discharging, it is deflected to the other side, thus showing at a glance whether the cells are charging or discharging. It should be noted that the + side of the dynamo is connected to the + side of the battery

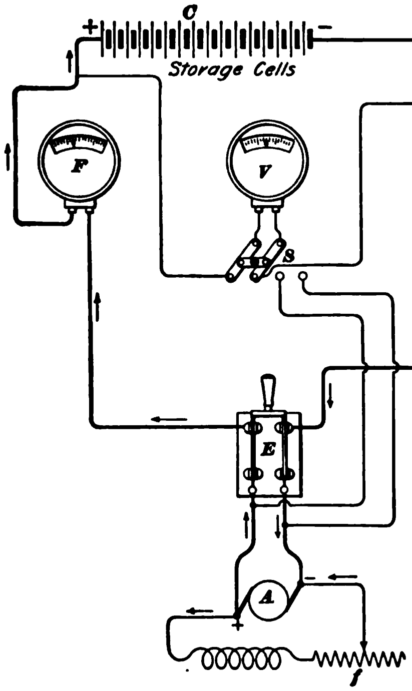

FIG. 52.

when the switch is thrown in, the direction of the charging current being indicated by the arrows. In this case, we have assumed that the number of cells to be charged is sufficiently great to take up the voltage of the dynamo; if this were not the case, a resistance would have to be inserted in series with the battery, as previously explained.

**64.** Having made sure that the connections are all right, see that switch *E* is open and get the dynamo up to speed.

Then measure the voltage of the cells and adjust the field rheostat of the dynamo until the voltage of the latter is from 5 to 10 per cent. higher than that of the cells. Throw in the main switch and adjust the rheostat until the ammeter indicates the charging current called for by the makers of the cells. When the cells are charged for the first time, some makers recommend that they be charged at about one-third the usual rate for the first 3 hours. As the cells become charged, the voltage of the dynamo must be increased, by cutting out field resistance, in order to maintain the charging current. Charging at a rate higher than that allowed by the makers is almost sure to injure the cells in time. Charging at a low rate is, in some cases, beneficial when the cells are not in good condition; but if the cells are all right, slow charging is of no particular benefit and consumes time. By keeping track of the length of time the battery has been charging, the attendant can usually tell when the cells are fully charged. If the cells happen to be overcharged a little, it does them no harm, but it results in a waste of current. Other things besides the number of ampere-hours supplied point out the fact that the cells are fully charged; the positive plates become a dark-chocolate color, almost black; the voltage across each cell rises to about 2.5 volts. Another indication of a fully charged cell is "gassing." When the cell is fully charged, oxygen and hydrogen are given off freely because they are no longer able to combine chemically with the plates, and after a cell has been gassing 10 or 15 minutes it may be assumed that it is fully charged. These gases fill the electrolyte with minute bubbles and make it milky in appearance. The bubbles rise to the surface and make the electrolyte appear as if it were boiling.

**65. Simple Switchboard for Storage Battery.**—The outfit shown in Fig. 52 is sufficient where a battery is simply to be charged and where a fairly close watch can be kept on it while the charging process is going on. Generally, however, the connections must be arranged so that the cells may be either charged from the dynamo or allowed to discharge into the line. It is also necessary to have fuses or an automatic circuit-breaker of some kind to protect the battery against overloads. An *underload switch* is, also, connected between the cells and the dynamo, as indicated by the dotted outline *K*, Fig. 52. The duty of this switch is to prevent the cells from discharging into the dynamo and running it as a motor. It is, usually, an automatic switch controlled by an electromagnet connected in series between the dynamo and the battery. If for any reason the current drops to a very low value, the electromagnet releases its armature, thus opening the switch and disconnecting the cells from the machine.

**66. Automatic Overload-and-Underload Switch.**—Fig. 53 shows a special automatic switch designed to protect the dynamo from any backward rush of current and, also, to protect the battery from overloads. Two coils *a* and *b* are connected in series between the battery and dynamo, as indicated at *K*, Fig. 52. If the current becomes excessive, coil *b* pulls up a core that releases a trip and causes the arm to fly out, thus breaking the circuit at *d*, *d*. When the battery is charging, coil *a* holds its armature, but if the current becomes very small, as it must do before it begins to reverse and flow back from the batteries, the armature is released, which action releases the catch and allows *c* to fly out. The instrument is, therefore, a protection against both underloads and overloads.

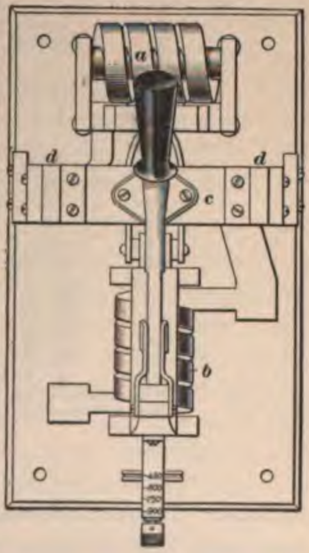

FIG. 53.

For example, a battery might be charging and the speed of the dynamo might drop or the belt fly off. In either case, the voltage of the dynamo would drop and the charging current fall to zero. If the circuit were not opened, a current would flow from the battery through the dynamo and run it as a motor. Another instance in which damage might result if an underload switch were not used is in case the field circuit of the dynamo should happen to become

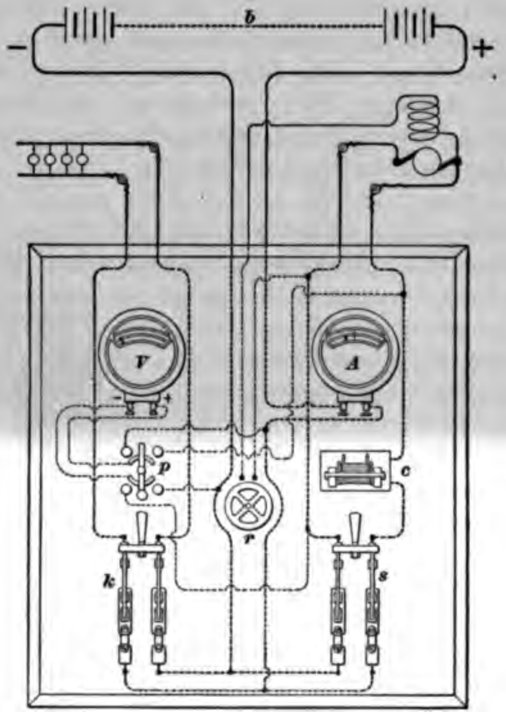

FIG. 54.

broken. This would reduce the E. M. F. of the dynamo to zero and a large rush of current could take place through the armature, because the cells would be unable to excite the field so as to enable the machine to generate any counter E. M. F. as a motor. In the case of a compound-wound dynamo, a backward rush of current might result in a reversal of the dynamo field. In the case of a simple shunt dynamo, the current flows around the shunt in the same direction no matter whether the dynamo is charging the battery or whether the battery is forcing current back through the dynamo.

**67.** Fig. 54 shows a simple switchboard suitable for a small plant where a battery is used in conjunction with a dynamo for lighting or other purposes; *k* and *s* are two double-pole knife switches provided with fuses. The switch *k* controls the lighting circuit and switch *s* is connected to the dynamo *d* through the underload circuit-breaker *c*. The ammeter *A* is connected in series with the battery *b* and indicates the charging or discharging current. *V* is a voltmeter connected to a switch *p*, by means of which *V* may be connected across either the dynamo or the battery; *r* is the handle of the field rheostat that is connected in series with the shunt field of the dynamo. The rheostat is located behind the board. When the battery is being charged, the switch *k* is open and the switch *s* closed. When the battery alone is furnishing current to the line, *s* is open and *k* closed. If it is desired to have both battery and dynamo furnish current to the line, both switches are closed.

**68. Discharging.**—When a battery has been fully charged, it will retain its charge for a considerable length of time without serious leakage. The amount of leakage will depend on how well the cells are insulated. Except where the cells are used for portable purposes, they are usually discharged within a few hours after they are charged; in fact, in most railway or power stations the charging and discharging go on intermittently, charging occurring on the line when the load is light and discharging when it is heavy. The maximum discharge current is usually about the same as the charging current, though sometimes it is allowed to run slightly higher without damage. The maximum discharge current that may be taken from a cell depends largely on its construction and is usually specified by the makers. Heavy discharge currents are liable to heat the cells and break up the plates by causing pieces of the active material to fall off. It is very bad practice to allow an accumulator to become completely discharged, as it is almost sure to give rise to a trouble called **sulphating,** and this, in turn, is liable to cause buckling of plates. It is always well to leave about one-quarter of the charge in the cells and never to discharge them to such an extent that the voltage per cell drops below 1.9 or 1.8 volts.

**69. Sulphating.**—This is one of the things that gives considerable trouble in connection with storage cells and which, if allowed to go too far, may render them almost useless. It has been stated that lead sulphate $PbSO_4$ is formed when the cells are charged or discharged. The formation of this sulphate is necessary in connection with the operation of the cell and it does no harm whatever. There is, however, another lead sulphate $Pb_2SO_5$, and it is this one that is generally credited with causing the trouble known as sulphating. This sulphate forms a white coating on the plates and generally accumulates more or less irregularly in patches. The white insoluble sulphate scale is very hard to get rid of and it prevents any action upon the portion of the plate that it covers. Because of this fact, it is responsible for a large portion of the buckled or bent plates that are sometimes found in cells. The patches of sulphate allow the plate to be acted upon in spots only and, as the active material expands and contracts when the chemical changes take place, the uneven expansion and contraction are liable to buckle the plate or cause the active material to fall off. As already stated, overdischarging is very liable to cause sulphating. It may also be caused by using too strong an electrolyte; i. e., an electrolyte having too large a percentage of acid in it. Also, if the cells are left standing for a long time without being charged, their charge may leak off and sulphating set in. If the sulphating has not gone far, the plates may be taken out and the white scale removed by scraping carefully. After this has been done, the cells should be charged at a low rate for a long time.

The positive plate generally gives the most trouble in storage batteries, hence this plate should be carefully watched for any signs of sulphating, buckling, or falling off of active material. If cells are to be left for a considerable length of time without being used, they should first be fully charged, the electrolyte drawn off, and the cells filled with clear water. They should then be allowed to discharge at their normal rate, which they will do for a short time only. After the water has stood in the cells for about 36 hours, it may be drawn off and the cells will remain in good condition until they are again put into commission.

**70. General Remarks.** — A storage battery, to give good service, must, like everything else, be kept in good condition. This means constant inspection of the plates and the condition of the electrolyte. The cells must be watched to see that none of them become short-circuited by particles becoming lodged between the plates or by material accumulating in the bottom of the cells. Cells should not be charged or discharged at an excessive rate for any length of time, though many of the batteries now manufactured will deliver heavy currents for short intervals without perceptible damage. Plates of the Planté type, i. e., with formed material, will, it is claimed, stand heavy charges and discharges better than those of the Faure, or pasted, type, which is a feature of considerable value in connection with automobile or other portable batteries. If plates become slightly buckled, they may be straightened by being pressed between boards—they should not be pounded. Battery rooms should be exceptionally well ventilated because of the fine acid spray that is formed when the cells are in operation. The bubbles of gas bursting at the surface of the acid throw off a very fine spray of acid that is extremely irritating. Different methods have been tried to keep this spray from being thrown off, such as pouring a layer of oil on top of the electrolyte or pouring melted paraffine on the surface. In the latter case, the paraffine hardens and seals the cell. A small hole about ¼ inch in diameter, or two or three of such holes for a large cell, must be left to allow the gas to work its way out and also to permit the insertion of the hydrometer. The best method, however, of doing away with the trouble is to provide thorough ventilation.

### REGULATION OF STORAGE BATTERIES.

**71.** Storage batteries in connection with large central stations are used in a number of different ways that will be taken up more in detail in connection with *Electric Lighting* and *Electric Railways*. In electric-lighting work, they are usually charged during the day and used to help out the dynamos at night, when the heavy load comes on. They are also used in some cases to carry the whole load during intervals when the demand is light. In railway work, they are generally left connected all the time the road is in operation; they are so arranged that they will become charged during the intervals when the load is light and will discharge when the load becomes heavy.

Since the voltage drops as the battery discharges, it is necessary, when they are used in connection with lighting work, to have some means of maintaining the pressure supplied to the line at a constant value. This is generally accomplished by having a few extra cells that may be switched into service by automatic switches as the voltage of the battery drops. In railway work, the regulation of the battery must be effected rapidly in order to make the battery charge or discharge with the rapid fluctuations in load peculiar to railway service. This is usually accomplished by means of a so-called *booster*.

The **booster** is a comparatively small dynamo of special design that is driven at a constant speed by a steam engine, or, what is more usual, by a direct-connected electric motor. The general action of a **differential booster** will be understood by referring to Fig. 55. The armature $A$ of the booster is connected in series with the battery, so that whatever voltage may be generated in it will be combined with that of the battery. In other words, varying the E. M. F. in *A* has practically the same effect as varying the E. M. F. of the battery by adding or cutting out cells. For example, the batteries will be charging whenever the voltage between the points *a*, *b* falls below that of the generator *G*, and they will discharge whenever it rises above that of *G*.

The field of the booster is provided with two windings, one of which consists of a few turns of heavy conductor and is connected in series with the line; the other winding is of fine wire and is connected in shunt across the battery as shown. A rheostat is provided in this shunt circuit so that the field current may be adjusted. The effect of the series coil may be adjusted by means of a low-resistance shunt *r* connected across its terminals. The full-line arrows represent the course of the current when the cells are helping out the generator and the dotted arrows show the flow of current when the cells are charging. The shunt field of the booster supplies a practically constant magnetizing force because the current through the shunt remains almost the same, no matter whether the cells are charging or discharging, and the direction of the current in the shunt also remains the same. The series coils are so connected that the current passing out to the line circulates around them in a direction opposite to that in the shunt coils. The

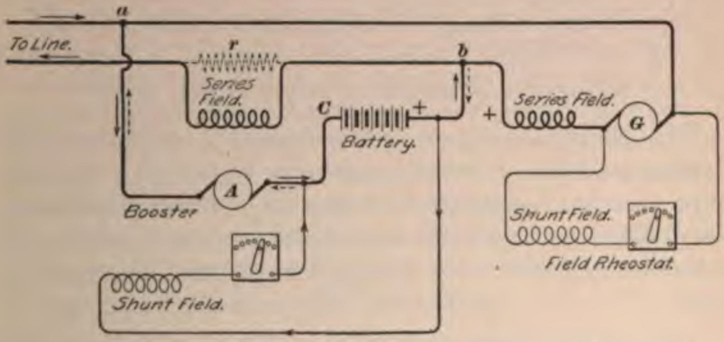

FIG. 55.

windings are so adjusted that when the normal load is being delivered, the two coils balance each other and the booster armature generates no E. M. F. Suppose the current required on the line falls below the average or normal output. The shunt coil will then predominate, and the booster will generate an E. M. F. which is directed so that it is opposed to that of the cells (see direction of dotted arrows through booster), or in the same direction as that of the generator; hence it helps the generator to send current through the cells, as shown by the dotted arrows. When the line current becomes greater than normal, the series coil predominates, the booster E. M. F. is reversed and helps the battery to discharge and help out the dynamos. All that the booster does is simply to bring about a raising or lowering of the pressure between the points *a*, *b* so that the battery will charge or discharge at the proper time.

**72.** The preceding is intended merely to illustrate the general principle of booster regulation as used in connection with batteries. A number of patents have been taken out for different schemes of connections for this purpose, and the above is not, by any means, the only one that might be used.

**73. Edison Storage Battery.**—All that has been said in the foregoing relates to the ordinary lead-sulphuric acid storage cell, because this is the only type which has hitherto been used to any extent in practice. A new cell has recently been brought out by Edison which it is expected will be lighter and more durable than the older type. Whether this will prove to be the case remains to be seen, as the cell has not yet been used commercially on a large scale. The positive pole, or the plate at which current flows out when the cell is discharging, is a superoxide of nickel. The negative pole, or plate at which the current flows in when the cell is discharging, is iron. The electrolyte is a solution of caustic potash in water—about 20 per cent. of caustic potash is used. The plates are made of sheet steel and have openings in which fit small perforated flat steel boxes which contain the active material. This cell gives an E. M. F. of 1.5 volts after being recently charged and an average voltage during discharge of 1.1 volts. It gives an output of 14 watt-hours per pound, which is equivalent to a weight of 53.3 pounds per horsepower-hour. It will be noticed that it is about two and one-half times as light as the lead cell for the same output, so that if it proves satisfactory in other respects, it will have a great advantage over the older type of accumulator.

## COMBINED RUNNING OF DYNAMOS.

**74.** In preceding articles relating to the operation of dynamos in connection with power-transmission work, we have assumed, in nearly all cases, that each dynamo was operated by itself and that it fed into its own line or feeder. Where a station is equipped with a number of dynamos and circuits, it is often very desirable to have the machines arranged so that they may be operated together; generally in parallel, though in some cases in series. We will, therefore, take up some points relating to the combined operation of machines, both direct and alternating.

### DYNAMOS IN SERIES.

#### DIRECT-CURRENT MACHINES.

**75.** Dynamos are not very often run in series. Perhaps the most common case is where they are run in pairs of two in series on the three-wire system. Of course, whenever dynamos are connected in series, their pressures are added in the same way that the voltage of two or more cells of battery is added when they are connected in series. The current output is not increased. The use of dynamos in series on the three-wire system has already been explained, so that there will be no need to dwell on it further at this point. Sometimes when shunt-wound dynamos are operated in series, the shunt coils are connected in series also, so as to form a single shunt across both machines. In other cases, the shunt fields are connected so that the shunt of one machine is excited from the armature of the other. The object of using these different methods of connecting the shunt coils is to make the voltage divide equally between the machines, so that each will do its proper share of the work. Series-wound dynamos are sometimes operated in series, especially in connection with arc lighting. In this case, the connections are very simple, about the only precaution being to see that the positive pole of one machine is connected with the negative pole of the other, so that the pressures of the two machines will be added together instead of opposing each other. Generally speaking, series-wound, shunt-wound, or compound-wound machines may be run in series with very little difficulty; in the case of the last-named type, the compound coils must, of course, be connected in series in the line. In most cases, however, the demand is for a large current output rather than for a high voltage, hence plain series running is not very common, except, perhaps, on arc-light circuits, where a high voltage may be required for operating a large number of lamps in series.

## ALTERNATORS.

**76.** Alternators cannot be run in series unless their armatures are rigidly connected by being mounted on the same shaft, so that the E. M. F.'s generated by the two machines will always preserve exactly the same relation with regard to each other. If the machines are driven separately, the E. M. F.'s may aid each other at one instant and oppose each other the next, thus making their operation unstable. For this reason alternators are very seldom operated in series.

## DYNAMOS IN PARALLEL.

### DIRECT-CURRENT MACHINES.

**77.** Dynamos, both direct and alternating, are much more frequently operated in parallel than in series. Nearly all modern electric-light, electric-railway, or electric-power-transmission plants are arranged so that the machines may be operated either singly or in parallel. When two dynamos *A* and *B* are connected to a line, as shown in Fig. 56, they are in parallel. Each machine generates the same voltage, and the pressure between the lines is the same as if a single machine were used; i. e., the pressure between the lines is not increased by adding machines in multiple, but the current delivered to the line is increased because the line current is the sum of the currents delivered by each of the machines.

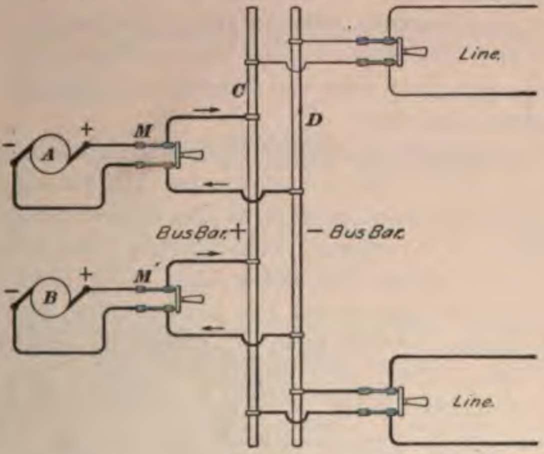

FIG. 56.

Each machine is connected through its main switch *M*, *M′* to the heavy conductors *C*, *D*, like terminals of each machine being connected to the same bar. As shown in the figure, the two positive terminals are connected to *C* and the two negative to *D*. Care must be taken to see that like terminals are always connected to the same bar. Each machine, when so connected, delivers current to the main bars $C$, $D$ and thence to the line. In fact, the whole arrangement is very similar to the steam piping between a battery of boilers and the engines. The dynamos correspond to the boilers and the bars $C$, $D$ to the main steam pipe, or header, into which the various boilers feed; the lines running from $C$, $D$ correspond to the steam pipes running to the engines. The bars $C$, $D$ are called **bus-bars**; these bars carry all the current supplied by the machines, and it is delivered from them to the various lines. The bus-bars are generally heavy copper bars mounted on the back of the switchboard, and will be described more in detail in connection with the subjects of *Electric Lighting* and *Electric Railways*.

It is not as easy a matter to operate machines in parallel as in series. It is evident that the voltage of each of the machines must be kept at the proper amount if the combination is to operate satisfactorily; for, suppose the E. M. F. of $B$ should fall below that of $A$, then $A$ would send current through $B$ and run it as a motor, and $B$ would thus be taking current from $A$ instead of helping it feed into the line. There are a number of things that must be taken into account when machines are run in parallel that do not have to be considered when they are run separately. Compound-wound machines are run in parallel more than any other type in this country, though shunt machines are frequently run in this way also. Series machines are seldom run in parallel for reasons to be given later. We will, however, first consider the series machine briefly, because the compound-wound machine is a combination of the series- and shunt-wound machines and a glance at the operation of the series dynamo will help to make clear the performance of the compound dynamo.

### SERIES-WOUND DYNAMOS IN PARALLEL.

**78.** Suppose we have two series-wound dynamos in parallel, as shown in Fig. 57, and assume that they are delivering current to a load of some kind and that each machine supplies, say, one-half of the current. Now, if the E. M. F. of one of the machines *A* drops slightly, due to a slight variation in speed or any other cause, the amount of current delivered by *A* will decrease, and thus decrease the field excitation, because the current through the field coil is the same as the current delivered by *A*. This lowering of the field excitation of *A* will still further cut down its E. M. F. and matters will go from bad to worse until, in a very short time, *A* will be driven as a motor, unless the belt on the heavily loaded machine should slip and thus bring down its voltage. The trouble is made still worse by the fact that the extra load thrown on *B* will raise its E. M. F., because the field of *B* will be strengthened. Moreover, when *A* is run as a motor, its direction of rotation will be reversed; and this may result in considerable damage. It is thus seen that two series-wound machines connected in parallel, as shown in Fig. 57, will be very unstable in their action, and it is not practicable to so operate them.

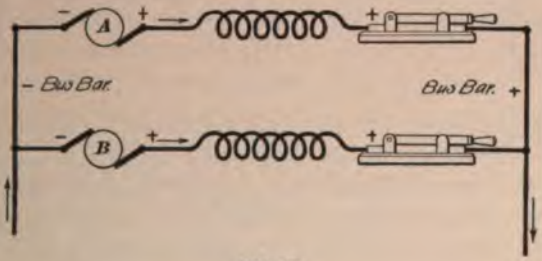

FIG. 57.

**79. Equalizing Connection.**—The unstable condition just referred to can be remedied in a large measure by using an equalizing connection, or **equalizer,** as it is commonly called. This is shown in Fig. 58, where the wire *c d* is the equalizer. The equalizer is a wire of low resistance connecting the points *c*, *d* where the series coils are attached to the brushes; *e*, *f* are the regular terminals of the machine, and the student should note carefully what points are connected by the equalizer. Now suppose that the machine *B* delivers a greater current than *A*; part of this current will flow to the + line through the coil *d f*, but part of it will, also, take the path *d–c–e* through the field coil *c e* of machine *A*. The result is that part of the current delivered

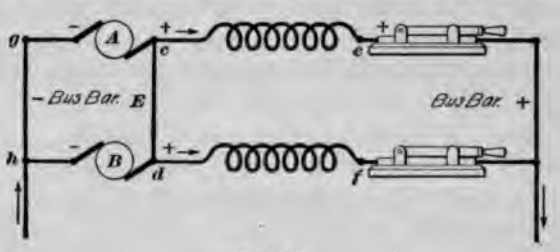

FIG. 58.

by *B* helps to keep up the field excitation of *A*, thus bringing up its voltage and equalizing the load between the machines. If *A* delivers the greater part of the load, due to a drop in the voltage of *B*, then part of the current flows through the path *c–d–f* and strengthens the field of *B*.

**80.** Even if the equalizer is used, there is another difficulty in the way of operating series machines in multiple that might not appear at first glance. Suppose that one series dynamo is carrying a load and that the load is increasing so as to make it necessary to put another machine in parallel with it to help it out. Now, in order to throw a dynamo in multiple with another dynamo that is already running under load, the dynamo that is to be thrown in must admit of having its voltage brought up to an amount equal to, or slightly greater, than that of the machine already in operation. If this were not done, the second machine would simply short-circuit the first as soon as a connection was made. Also, a series machine when run as a dynamo cannot generate any voltage unless it is allowed to deliver current, because the field coils are in series with the main circuit; so that in order to get the second machine up to voltage, we must either separately excite it in some way or provide a temporary load of some kind and then so arrange it that the machine can be thrown over on to the main load. Either of these schemes will introduce complications. It is thus seen that the series dynamo is not at all well adapted for parallel running. The above points will, however, be of assistance in understanding the action of the compound-wound dynamo.

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### SHUNT DYNAMOS IN PARALLEL.

**81.** Shunt dynamos will operate very well in parallel and have been largely used in this way. They have two properties that make their parallel operation a comparatively easy matter. In the first place, they are capable of exciting their own field no matter whether they are delivering current to the main circuit or not. In the second place, their voltage drops slightly with an increase in the load, and this tends to make their parallel operation stable, as will be shown later. Suppose that we have two shunt machines arranged as shown in Fig. 59; *A* and *B* are the armatures of the two shunt machines, *S*, *S'* are the shunt field windings, and *r*, *r'* the adjustable field rheostats. *L*, *L'* are switches in the field circuit and *M*, *M'* main switches connecting the machines to the line. We will suppose that machine *A* is in operation, as indicated by the closed position of switches *L* and *M*. If now we wish to throw machine *B* into multiple, it is run up to speed and the switch *L'* closed; *B* will at once begin

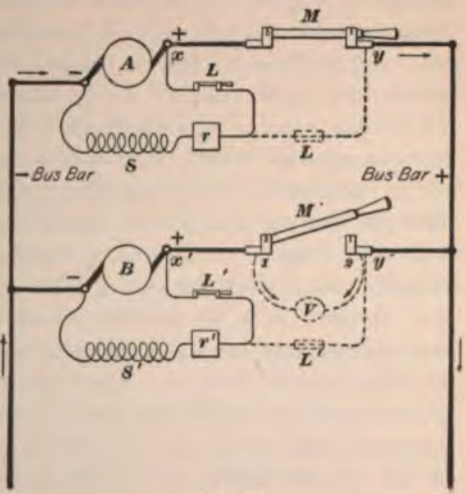

FIG. 59.

to pick up its field and run up to voltage. If the two machines are generating the same voltage and if their polarity is the same, as it should be, a voltmeter connected to blocks *1*, *2* will give no deflection, because the tendency of the machine *A* to send current through the voltmeter will be opposed by *B*. This state of affairs can be brought about by adjusting the rheostat $r'$ until the voltmeter indicates that the voltages of the machines are equal. After this has been done, the switch $M'$ may be closed and the field excitation of *B* again adjusted until the proper share of the load is carried. It is thus seen that there is no particular difficulty in throwing one shunt machine in parallel with another, because it can easily be brought up to the desired voltage, since the field circuit is independent of the main circuit. In practice, it is generally found better to have the voltage of *B* about 1 or 2 per cent. higher than that of *A* when the machine is thrown in.

Sometimes, when shunt machines are arranged for parallel operation, the field is connected across the mains instead of across the armature of each machine. When this is the case, the field connection is made as indicated by the dotted lines $r\,y$, $r'\,y'$, instead of being connected as shown by the full lines $r\,x$, $r'\,x'$. The effect of this is that the switch *M* must be closed before *A* will pick up, assuming that *B* is not in operation. If *A* is running and *B* is to be thrown in, then the switch $L'$ is closed and *B*'s field is at once excited from the mains, so that *B* comes up to voltage almost immediately; after the voltage has been adjusted, switch $M'$ may be thrown in as before. The reversal of the shunt-field connections on a dynamo that is to run in parallel with another dynamo is apt to give rise to trouble. If the field is connected, as shown by the full lines Fig. 59, so that the machine must supply its own field current before the main switch can be closed, no trouble is liable to arise; because, with the wrong field connection, the dynamo cannot generate and the dynamo tender or switchboard attendant will notice that the machine does not pick up and will naturally look for the trouble. If, however, the field is connected in beyond the main switch or across the station mains, as shown by the dotted lines, the machine becomes separately excited from the other dynamos that happen to be in service. It therefore generates an E. M. F. that is in just the opposite direction that it should be, and when the machines are thrown together, a rush of current takes place through the machine with the reversed field because its E. M. F. is in the wrong direction to keep out the current from the other machines. The result is, therefore, equivalent to a bad short circuit. Reversal of the shunt-field connection is not a common occurrence, but it has been known to happen where it has been necessary to disconnect the connections for purposes of repair or in order to move the dynamo.

**82.** We will suppose that the two shunt machines, Fig. 59, are running properly in multiple and will now see whether their operation will be stable or not. It has already been said that one property of the shunt dynamo is its tendency to drop its voltage as the current output increases. This fact is due principally to the drop in the armature and the armature reaction, as explained elsewhere. Now suppose that the voltage of *A* should drop slightly on account of a drop in speed or from any other cause. The tendency will be to throw the bulk of the load on *B*, with the result that *B*'s voltage will also drop on account of the above-mentioned property of the shunt-wound dynamo. The dropping of *B*'s voltage will relieve it of part of its load and will make it divide with *A*. It is thus seen that there is an automatic tendency for the load to equalize. Again, suppose that each machine is carrying a certain load and that the load on the line is suddenly increased, and that machine *B* takes more than its share of the current; the large current delivered by *B* will cause its E. M. F. to drop to more nearly that of *A*, and the load will thus be equalized. If the voltage of one machine should for any reason become so low that the other machine runs it as a motor, no harm is liable to result, because the direction of rotation of the machine as a motor will be the same as it is when being driven by the engine as a dynamo. As far as parallel running goes, the shunt-wound dynamo is satisfactory, but it has been replaced by the compound-wound machine, because the latter will maintain the line voltage with an increase of load; whereas, with shunt-wound machines, the line voltage will fall off, unless the switchboard attendant cuts out some field resistance.

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### COMPOUND-WOUND MACHINES IN PARALLEL.

**83.** Since the compound-wound machine is a combination of the series and shunt machines, one would naturally infer that the arrangement for parallel running would be a combination of the two preceding ones. Fig. 60 shows the connections in their simplest possible form; we have two machines *A* and *B* of equal size and the equalizer *E* running directly between them; *c* and *f* are the + terminals of

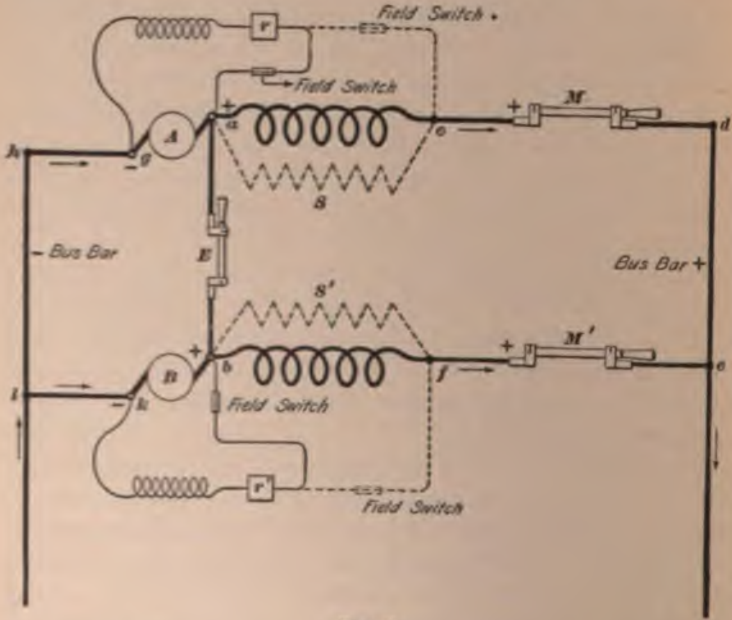

FIG. 60.

the machine, while *c d* and *f e* represent the leads, or cables, running to the switchboard; *g h* and *k l* are the negative leads running to the negative bus-bar *h l*. There would be, in practice, a main switch in each of these negative leads, but as they are not essential for the present purpose they have been omitted, so as to make the figure as simple as possible. As shown by the full lines in Fig. 60, the shunt windings of the machines are connected in what is known as **short shunt**; i. e., the shunt field is connected across the brushes. Sometimes the shunt field is connected in **long shunt** across the terminals of the machine, as indicated by the dotted lines *r c* and *r' f*. It makes very little difference as to the performance of the machine which connection is used.

Most compound-wound machines are provided with low-resistance shunts *S*, *S'* across their series coils in order that the degree of compounding may be adjusted. When machines are operated in parallel, these shunts should be adjusted so that the machines, when running separately, will give the same degree of compounding, which means, in the present case, that when each machine is delivering the same current, the voltage generated will be the same, because we are now assuming that *A* and *B* are of equal size. Another condition that must be fulfilled is that the resistance between the points *a* and *d* must be the same as between *b* and *e*. Since we are, for the present, assuming that the machines are of the same size and make, the resistance of their series coils *a c* and *b f* will be almost exactly the same. The resistance of the switchboard leads *c d* and *f e* must be the same, i. e., of the same length and cross-section; the resistance of the equalizer *E* should be as low as possible, and it should never be more than the leads *c d* or *f e*.

**84.** We will now examine the action of the machines under a varying load. In the first place, if the resistance between *a d* is equal to that between *b e* and the machines are delivering equal currents, then the drop through *a d* will equal the drop through *be* and points *a* and *b* will be at the same potential. Since current can only flow between points at different potentials, there will be no current in *E* under such circumstances. Suppose, however, that *A* delivers a greater current than *B*; then the drop in *ad* will exceed that in *be* and current will flow through the path *a–E–b–f–M′–e* and thus build up the voltage of machine *B* and equalize the load. If *B* delivers more current than *A*, the drop in *be* exceeds that in *ad* and current flows through the path *b–E–a–c–M–d*, builds up the voltage of *A*, and makes *A* take its share of the load.

**85.** In Fig. 60, the equalizer *E* is shown as connecting the positive brushes. This is usually the case in practice, though it would work just as well if both *a* and *b* were negative brushes and *c*, *f* the negative terminals of the machines.

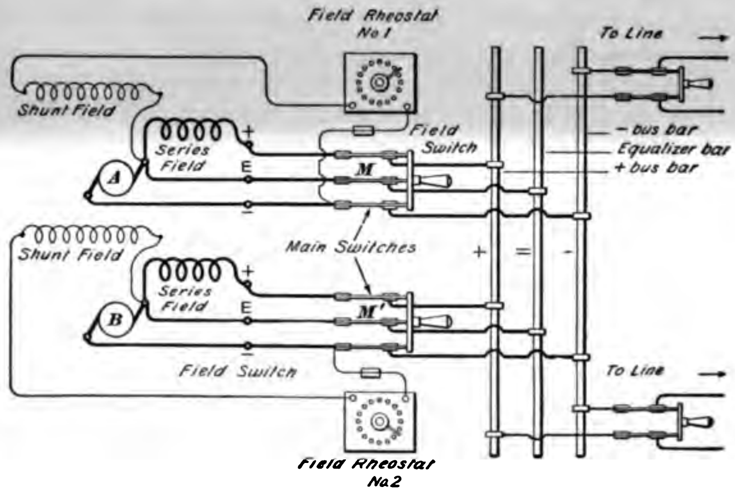

FIG. 61.

The only thing that must be looked out for is to see that the equalizer connects the brushes to which the series coils are attached, and also to see that these brushes are of the same polarity. In some cases, the equalizer wire is run directly between the machines, as shown, but often a third wire is run from points *a* and *b* to the switchboard and there connected to an equalizer bar, as shown in Fig. 61. This represents a very common arrangement, triple-pole switches being used; the two outside blades for the + and − leads and the middle blade for the equalizer. There is a difference of opinion as to whether it is better to run the equalizer to the switchboard or run it directly between the machines, as in Fig. 60. The most recent practice tends towards running it directly and placing the equalizer switch near the machine. This undoubtedly tends to make the connections shorter and thus leads to better regulation. In such cases, the equalizer switch is usually mounted on a pedestal near the machine, as shown in Fig. 62.

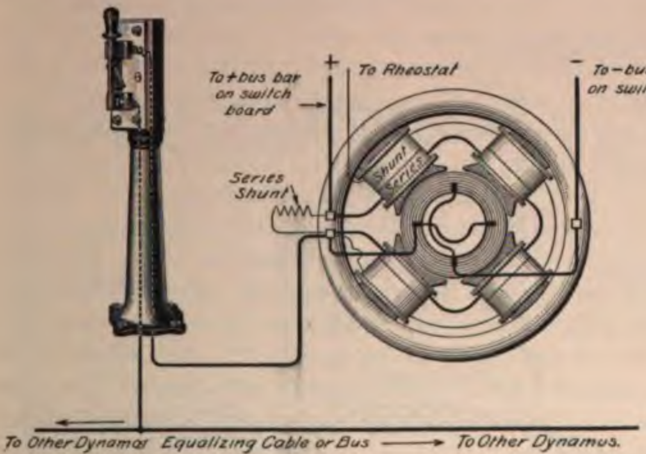

FIG. 62.

**86.** So far, in all that has been said, the machines were supposed to be alike in size and general design. Under such circumstances, there is generally no great difficulty in getting compound-wound machines to operate properly in parallel. Trouble is often experienced, however, when it comes to operating machines of different construction and size.

Some field magnets will respond to changes in field excitation much more quickly than others, and other differences in design may have considerable effect on the performance of the machines when they are run in parallel. When running two machines of different size in parallel, the problem is to get the load to divide between them in proportion to their size. For example, suppose we have a large machine *A* connected in parallel with a smaller machine *B*, as shown in Fig. 63. Each machine is supposed to be

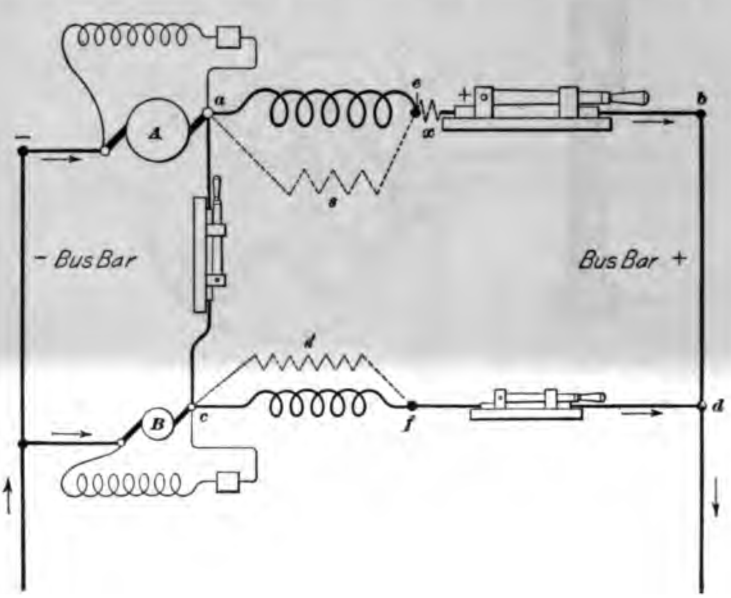

FIG. 63.

adjusted so that it gives the same degree of compounding when operated by itself. Also, when each machine is delivering its proper share of the load, the drop between *a b* must equal the drop between *c d*. For example, if *C* is the full-load current of *A*, *R* the resistance between *a* and *b*, *C'* the full-load current of *B*, and *R'* the resistance between *c* and *d*, then $C \times R$ must equal $C' \times R'$. Now, the resistance of the series coils cannot very well be altered in order to bring about the required condition of affairs, so that the only thing to do is to insert resistance of some kind in the leads *e b* or *f d* until the above drops become equal. This resistance will, of course, be very small and may be made up of a short piece of heavy German-silver strip or even an extra amount of cable in one of the leads. In the figure, this small additional resistance is indicated at $x$, though it may be necessary to insert it in the main lead of machine $B$. The resistance must be inserted in series with the machine giving the least drop between the points mentioned above. Many times the attempt is made to bring about the adjustment by changing the shunts $s$ $s'$, but such attempts are useless, because just as soon as the machines are put in parallel, $s$ and $s'$ are also in parallel and are practically equivalent to one large shunt across the fields of both machines. The consequence is that any change in the shunts affects both machines. The adjustment must, therefore, be made in the main lead between the series coil and the bus-bar, and any resistance so inserted must have the same carrying capacity as the series coils. A change in the shunt across the series coils will change the compounding of the machines as a whole, but it will not better their condition as regards the correct division of the load.

**87.** The above are some of the main features connected with the running of compound-wound machines in multiple. In street-railway work, the load fluctuates through wide ranges and with great rapidity, and the proper running in multiple there represents more difficulties than in any other line of work. For the present, all that we wish to call attention to are the important points connected with parallel running under normal conditions.

**88. Compound Machines in Multiple With Shunt Machines.**—It is not practicable to run a compound-wound machine in multiple with a shunt machine. If, for any reason, the compound-wound machine takes a little more than its share of the load, the strengthening of its series coils makes it still further overload itself, with the result that the field rheostat of the shunt machine calls for constant attention. The only way to run this combination satisfactorily is either to cut out the series coils of the compound-wound machine, thereby making both plain shunt machines, or else to provide the shunt machine with compound coils.

### ALTERNATORS.

**89.** Alternators may be operated in parallel, although they are, as a rule, more troublesome than direct-current machines. This is especially the case if they are very different in size and design. For example, alternators with the old-style, smooth-core armatures are hard to run in parallel with modern machines having toothed armatures. In fact, in many of the older lighting stations special precautions were taken at the switchboard to see that two alternators should never be thrown in parallel. In modern plants, however, parallel running is quite common, and if proper care is taken, the machines may be thrown together without danger.

**90.** Alternators are operated in parallel in much the same way as direct-current machines, so far as connections are concerned; i. e., they are usually connected to bus-bars through the intervening main switches. If the alternators are compound-wound, an equalizing connection should be used; but very many of these machines are operated with a separately excited field only and no equalizing connection is necessary, the whole scheme of connection corresponding more nearly to the running of shunt-wound machines in parallel.

Suppose that we have two single-phase alternators *A* and *B* connected in parallel. In order that the machines may operate properly and each take its proper share of the load, it is, of course, necessary to have their voltages equal. There is another important condition that must also be fulfilled; the machines must be in **synchronism.** By this is meant that the E. M. F. of *A* must come to its maximum value at just the same instant as the E. M. F. of *B*, or in other words, the electromotive forces of the two machines must vary in unison or be in phase with each other. This means that both machines must run at exactly the same frequency, for if this were not the case, they would get out of step. Before two alternators are thrown in parallel, equality of frequency is the most important condition to be fulfilled. A slight difference in phase will cause an exchange of current between the machines, but they will pull each other into phase if the frequencies are equal.

**91. Synchronizing.**—The state of synchronism is usually ascertained by means of **synchronizing lamps** placed on the switchboard and connected as shown in Fig. 64. *T*, *T'* are two small transformers having their primary coils connected to the alternators, as shown. It should be noted that similar terminals *1*, *1'* are connected to similar sides of the machines. The secondaries are connected in series

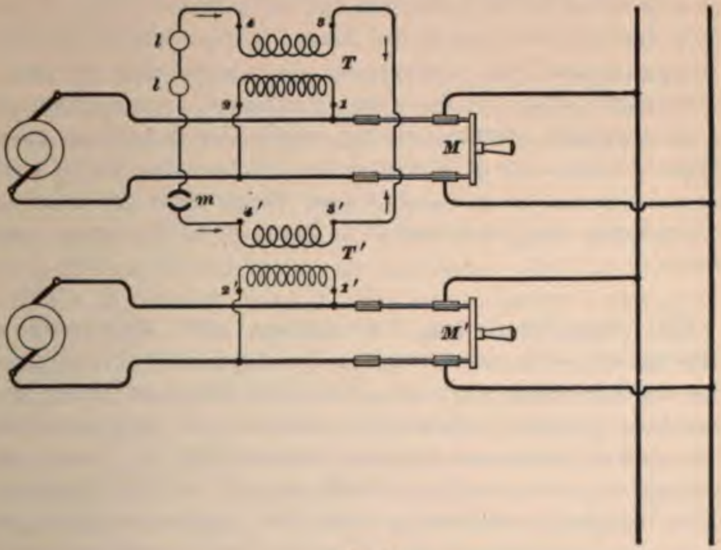

FIG. 64.

through a pair of lamps *l*, *l* and a plug switch *m*. If the machines are exactly in phase, terminals *3* and *3'* will have the same polarity at the same instant and the polarity of *4* and *4'* will also be alike. But since like terminals are connected together, the two secondary voltages will just neutralize each other, as indicated by the arrows, and the lamps will not glow. If the machines were directly opposite in phase, the lamps would light up to full candlepower. It is evident that by reversing the connections of one of the transformers the state of synchronism will be indicated by the lamps being bright, but we will assume that they are connected as shown in the figure. When machine *B* is started and the plug is inserted at *m*, the lamps rapidly fluctuate in brightness; but as *B* comes more nearly in synchronism the fluctuations become much slower. When they have become as slow as one in 2 or 3 seconds, the main switch *M'* is thrown in at the middle of one of the beats when the lamps are dark. In many cases, the connections are so made that the lamps are bright when synchronism is attained, because there is a considerable interval during which the lamps are dark. Whether the state of synchronism will be indicated by light or dark lamps depends simply on whether the transformer secondaries are connected so as to assist or to oppose each other.

**92. Synchronizing Two-Phase and Three-Phase Machines.**—Fig. 64 shows the synchronizing arrangement for a single-phase machine. For a two-phase or three-phase machine the same arrangement may be used, only care must be taken to make sure that the transformers *T*, *T'* are connected to corresponding phases on each of the machines. This may be determined by using two pairs of transformers; i. e., one regular pair, as in Fig. 64, and a temporary pair on one of the other phases. For example, on a two-phase machine an arrangement similar to that shown in Fig. 64 should be made for each of the phases, and when the connections are right, each set of phase lamps will light or become dark, as the case may be, at the same time, showing that both phases are ready for parallel operation. After it is known that the connections are all right, the temporary pair of transformers may be removed and only one pair used, as in Fig. 64.

**93. Synchronizing Instruments.**—A number of different styles of instruments have been designed to indicate when two alternators are in synchronism, and these are now used to a considerable extent in place of lamps. In some cases the lamps are replaced by a voltmeter. Another device consists of a pointer actuated by two small synchronous motors that are operated by the two machines to be synchronized. When the machines are in synchronism, these two small motors run at exactly the same speed. When they differ, the small motors run at different speeds, and the pointer on the dial indicates that the machines are out of synchronism.

**94.** If alternators are thrown in parallel before they are brought into phase, a heavy cross current will flow between them and damage may result. When they are running together, each alternator will hold the other in step and they will both run at such a speed as to give the same frequency; if they happen to have the same number of poles, the speeds will be exactly the same. Each alternator will deliver current in proportion to the power supplied it by the engine. The amount of current delivered by each alternator will also depend on its field excitation. If the field excitation of the machines is not maintained at the proper amount, there will be an idle current flowing between the alternators and the sum of the currents furnished by the machines will be considerably greater than the current delivered to the line. The field excitation should be such that the sum of the currents delivered by the individual machines will be as nearly as possible equal to the current delivered to the line. When running alternators in multiple, it is best to let one engine do most of the governing and have the second governor arranged so that it will act slowly and will let the first governor take care of the finer adjustments in speed. When machines are belt-driven, great care must be taken to see that the pulleys are exactly the correct dimensions to give the speeds required for operating in synchronism; because if this is not the case, there will be considerable belt slippage and there will also be considerable cross current between the two machines. The running in multiple of alternators coupled direct to engines often presents difficulties on account of the rotary motion of the engines not being absolutely uniform. This is especially the case if the engines are provided with light flywheels or poor governors. It does not take much angular variation between the two engines to throw the machines out of synchronism and thus cause cross currents to seesaw between the alternators. In cases where it is proposed to operate direct-connected alternators in multiple or direct-connected machines in parallel with belted machines, full details should be furnished to the manufacturers, so that the engines and dynamos may be fitted to this class of work.

**95.** All cables running from the dynamos to the switchboard should have a cross-section of at least 1,000 circular mils per ampere. If two machines are run in parallel, the equalizing cable should have a cross-section of 1,500 circular mils per ampere of the full-load current of the machines to which it connects. Generally speaking, the lower the resistance of the equalizer cables the better will the machines operate. All main leads running from the machines to the switchboard should be of a first-class quality of rubber-covered cable, and where high-tension alternating-current machines are used, special precautions should be taken to secure high insulation of the wires and avoid crossings as much as possible.

# A SERIES
OF
# QUESTIONS AND EXAMPLES
RELATING TO THE SUBJECTS
TREATED OF IN THIS VOLUME.

It will be noticed that the Examination Questions that follow have been divided into sections, which have been given the same numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until that portion of the text having the same section number as the section in which the questions or examples occur has been carefully studied.

# OPERATION OF DYNAMOS AND MOTORS.

## EXAMINATION QUESTIONS.

(1) Why should the operation of emery wheels, grinders, and speed lathes and the handling of coal not be allowed in the same room with dynamos and engines?

(2) (*a*) On what machines are copper brushes generally used? (*b*) How are copper brushes generally set?

(3) How are (*a*) copper and (*b*) carbon brushes shaped to fit the commutator?

(4) What does the odor of hot oil around a machine usually indicate?

(5) State three possible causes for the refusal of a direct-current shunt motor to start after the main switch has been closed and the starting device properly operated.

(6) To what may the sparking at the brushes of a dynamo be due? Give at least four causes of sparking.

(7) What test may be used to locate defects in an armature?

(8) How would you test the field coils of a dynamo to determine whether any of them were open-circuited or not?

(9) Why should neither ordinary oil, in any considerable quantity, nor emery cloth be used on commutators or brushes?

(10) Why are carbon brushes used on high-voltage dynamos, especially when they are subject to sudden and violent changes in the load that cannot be met by shifting the brushes?

(11) How are (*a*) high and (*b*) low bars in commutators remedied?

(12) What is the result of continually overloading a dynamo?

(13) How does a shunt motor act when the shunt field is opened while the motor is running?

(14) Give three different methods for starting up a rotary transformer.

(15) How does a short-circuited field coil on a shunt dynamo affect the other field coils?

(16) Describe at least one method for locating a short-circuited armature coil.

(17) In making a bar-to-bar test around an armature, what would be indicated (*a*) by an unusually large deflection of the galvanometer or other testing instrument used? (*b*) by an unusually small, or no, deflection?

(18) (*a*) What is the objection to having the pressure between a brush and the commutator too great? (*b*) What is the objection to having it too small?

(19) (*a*) What does a narrow scratch or several of them all around a commutator usually indicate? (*b*) What is the remedy?

(20) What is the advantage of staggering the brushes on a commutator and having end play for the armature?

(21) What would a grinding, rumbling noise, accompanied by excessive sparking and, perhaps, some slipping of the belt, indicate in a dynamo or motor?

(22) What would be the effect of having one field coil reversed in (*a*) a dynamo? (*b*) a motor?

(23) State two reasons why a simple shunt dynamo may refuse to generate when properly rotated at normal speed.

(24) How are synchronous motors generally started?

(25) If only one coil in a motor or dynamo armature, when revolving at normal speed in its own normal field, becomes abnormally hot, what defect is indicated?

(26) What does a broad scratch around the surface of a commutator indicate?

(27) How would you start an induction motor?

# DYNAMO-ELECTRIC MACHINERY.

## EXAMINATION QUESTIONS.

(1) What is the relation in a direct-current motor armature between the E. M. F. at the brushes, the counter E. M. F., and the drop or fall of potential through the armature ?

(2) Why will not an ordinary series-wound dynamo, without regulating devices, give a constant current through a circuit of varying resistance ?

(3) How is the Thomson-Houston constant-current dynamo regulated to give a constant current ?

(4) A certain series-wound motor is tested with a Prony brake, the distance from the center of the shaft to the point where the arm of the brake rests on the scale platform being 36 inches. The brake is tightened until the pressure on the platform is 27 pounds, when the following readings are taken: Current to motor, 25 amperes; volts at terminals, 480; speed, 900 R. P. M. (*a*) What is the output of the motor in H. P.? (*b*) What is its efficiency at this output ?

Ans. { (*a*) 13.88 H. P.
(*b*) 86.3 per cent.

(5) Draw a diagram showing the connections of a shunt-wound motor with main switch, reversing switch, starting resistance, and fuse box.

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(6) How may the speed of a direct-current shunt motor be varied?

(7) When two coils or sets of coils in an open-coil constant-current armature are connected in parallel by the brushes and the E. M. F. in one coil is less than that in the other, why does not a current flow from the coil having the higher E. M. F. around through the other?

(8) How may the speed of a direct-current series-wound motor be varied?

(9) (*a*) What three general methods of regulation are used with closed-coil constant-current dynamos? (*b*) Which of the three is most generally used?

(10) A certain motor, being tested with a Prony brake, is found to have 85 per cent. efficiency when taking an input of 33 amperes at 230 volts. If the arm of the brake is 2 feet long, from center of shaft to point where it rests on the scale platform, and the pressure on the scale platform is 20 pounds, at what speed (to the nearest whole revolution) is the motor running? Ans. 1,136 rev. per min.

(11) Why is the starting resistance of a shunt-wound motor not included in the field circuit?

(12) Why is it that there is no E. M. F. generated in the coil of a Westinghouse constant-current dynamo that is directly under a pole piece?

(13) What is the character of the current in the external circuit of open-coil constant-current dynamos?

(14) How many sets of brushes must be provided for a parallel- or lap-wound drum armature?

(15) How many sets of brushes need be provided for a series- or wave-wound drum armature?

(16) What limits the output of constant-current dynamos?

(17) What would be the successive combinations that any particular coil in the Thomson-Houston constant-current

dynamo makes with the other coils during a half revolution, starting from a position where it is not active ?

(18) A certain shunt-wound motor takes a current of 5 amperes at 125 volts when running free. Its armature resistance is .04 ohm and its field resistance 62.5 ohms. (*a*) What would be its output in H. P. when taking a current of 77 amperes at 125 volts ? (*b*) What would be its efficiency at this output ?

NOTE.—As the method of finding the output and efficiency that should be used in solving the above problem is not strictly accurate, four figures are enough to retain in calculations or results.

Ans. { (*a*) 11.76 H. P.
(*b*) 91.17 per cent.

(19) How is the E. M. F. of the Excelsior constant-current dynamo regulated to give a constant current ?

(20) How much current, relative to the total current output of the armature, flows in an armature conductor of a parallel- or lap-wound armature for a six-pole machine ?

(21) To reverse the direction of rotation of a motor, what changes in the connections are necessary ?

(22) What limits the output of a direct-current constant-potential motor ?

(23) On what quantities does the torque of a direct-current motor depend ?

(24) How may the applied E. M. F. of a direct-current motor be varied ?

(25) (*a*) In a series-wound drum armature does the strength of current in the armature conductors depend on the number of brushes used ? (*b*) How much current, relative to the total current output of the armature, flows in the armature conductors of a series-wound drum armature ?

(26) To what classes of work are (*a*) shunt-wound direct-current motors applicable ? (*b*) series-wound motors ?

(27) How are the devices for shifting the brushes of constant-current dynamos with closed-coil armatures usually thrown into or out of action ?

(28) Which armature winding, a parallel or series, is most suitable and why (*a*) for a machine that has to furnish a comparatively large current at a comparatively low voltage, and (*b*) for a machine that has to furnish a comparatively small current at a comparatively high voltage ?

(29) Why should the field circuit of a shunt-wound motor never be opened as long as the armature is connected in the circuit ?

# ALTERNATING CURRENTS.

## (PART 1.)

## EXAMINATION QUESTIONS.

(1) What is meant (*a*) by a cycle? (*b*) by an alternation?

(2) (*a*) What is meant by the frequency of an alternating current or E. M. F.? (*b*) What is meant when it is said that an alternating-current dynamo is a 60-cycle machine?

(3) What is the chief difference between a direct current and an alternating current?

(4) If an alternator generates an E. M. F. that passes through 15,000 alternations per minute, what is the frequency of the E. M. F. in cycles per second?

Ans. 125 cycles per sec.

(5) (*a*) When are two alternating E. M. F.'s or currents of the same frequency said to be in phase? (*b*) When are they out of phase?

(6) (*a*) Can two alternating currents that are in phase be added together in the same way as direct currents? (*b*) If an alternator supplies three circuits *A*, *B*, and *C* with 10, 20, and 25 amperes, respectively, and if the currents in all three circuits are in phase with each other, what is the total current furnished by the alternator? Ans. (*b*) 55 amperes.

(7) What is meant when it is said that one alternator is brought into synchronism with another?

(8) An alternator supplies two circuits $A$ and $B$ with currents of 8 amperes and 12 amperes, respectively. These two currents are not in phase with each other because one circuit supplies a load of lamps and the other a load of motors that have considerable self-induction. Will the total current supplied by the alternator be 20 amperes, and if not, will it be more or less than 20 amperes? Give reasons for your answer.

(9) If two currents are said to differ in phase by 60°, what part of a complete cycle does one lag behind the other?

(10) When are two alternating currents said to be in quadrature or at right angles to each other?

(11) What do you understand by (*a*) a two-phase system? (*b*) a three-phase system?

(12) A two-phase system is operated by means of three wires, the center wire serving as a common return. (*a*) If the current in each of the outside wires is 200 amperes, what will be the current in the common return wire? (*b*) If the voltage between each outside wire and the middle wire is 1,100, what will be the voltage between the two outside wires?

Ans. { (*a*) 282.8 amperes.
(*b*) 1,555.4 volts.

(13) Why is it not necessary to use a common return wire with a balanced three-phase system?

(14) An alternator supplies current to a balanced three-phase circuit. If at a particular instant the current in one wire $A$ is at its maximum value of 100 amperes and is flowing *out* from the alternator, what is the amount and direction of the currents in the other two wires $B$ and $C$?

Ans. 50 amperes flowing *in*.

(15) (*a*) What do you understand by the maximum value of an alternating current or E. M. F.? (*b*) What is

meant by the average value? (*c*) What is the relation between the average value and the maximum value for an ordinary smooth wave E. M. F. or current?

(16) (*a*) What is meant by the effective value of an alternating current? (*b*) What is its relation to the maximum value?

(17) (*a*) What is meant when it is stated that an alternating current of 50 amperes is flowing in a circuit? (*b*) What is the maximum value that the current reaches, and between what limits does the current alternate? (*c*) What is the average value of the current?

$$\text{Ans.} \begin{cases} (b) & 70.7 \text{ amperes, } +70.7 \text{ and } -70.7. \\ (c) & 45 \text{ amperes, nearly.} \end{cases}$$

(18) (*a*) What do you understand by the E. M. F. of self-induction? (*b*) If a continuous current is allowed to flow steadily through a coil of wire that is wound on an iron core, is any self-induced E. M. F. set up, and if not, why?

(19) (*a*) What is meant by the coefficient of self-induction or inductance of an electrical circuit or device? (*b*) What unit is used to measure the coefficient of self-induction? (*c*) Would a coil wound on an iron core have a greater coefficient of self-induction than the same coil wound on a wooden core, and if so, why?

(20) What effect has self-induction in an alternating-current circuit as regards the phase relation of the current and E. M. F.?

(21) If an alternating current is sent through a circuit containing self-induction, (*a*) what phase relation does the E. M. F. *of* self-induction bear to the current? (*b*) What phase relation does the E. M. F. *to overcome* the self-induced E. M. F. bear to the current?

(22) If a current of 5 amperes at a frequency of 60 cycles per second is sent through a coil having an inductance of .02 henry, what will be the induced E. M. F. set up in the coil? Ans. 37.7 volts.

(23) An alternating current is sent through a circuit in which the induced E. M. F. is 20 volts and the E. M. F. necessary to overcome resistance is 8 volts. What must be the value of the impressed, or applied, E. M. F.?

Ans. 21.54 volts.

(24) (*a*) What is meant by the reactance of a circuit? (*b*) To what is the reactance equal? (*c*) What unit is used to measure reactance?

(25) (*a*) What is meant by the impedance of a circuit? (*b*) To what is the impedance equal? (*c*) In terms of what unit is impedance expressed?

(26) Give the formula showing the relation between the current, the applied E. M. F., and the impedance; in other words, give the form that Ohm's law assumes for alternating-current circuits.

(27) An alternator supplies current at 60 cycles to a circuit that has a resistance of 20 ohms and an inductance of .1 henry. The applied E. M. F. is 1,000 volts. Find (*a*) the reactance of the circuit; (*b*) the impedance; (*c*) the current that will flow under the applied pressure of 1,000 volts; (*d*) the current that would flow if the circuit had no self-induction.

Ans. (*a*) 37.7 ohms, approximately.
(*b*) 42.7 ohms, approximately.
(*c*) 23.4 amperes.
(*d*) 50 amperes.

(28) What effect has electrostatic capacity on the phase relation of the current and the E. M. F. in an alternating-current circuit?

(29) If an alternator supplies current to any circuit or electrical device and if the current and E. M. F. differ in phase, can the number of watts expended be obtained by multiplying the number of volts by the number of amperes, as in the case of direct-current circuits, and if not, why?

(30) (*a*) What is meant by the power factor of an alternating-current circuit or device? (*b*) What is the value of

the power factor for direct-current circuits or for non-inductive, alternating-current circuits ?

(31) An alternating-current motor when carrying a certain load took 50 amperes at 100 volts, as measured by an ammeter and voltmeter. When a wattmeter was connected, it was found that the actual number of watts supplied was 4,200. What was the power factor of the motor for the given load ? Ans. .84.

# ALTERNATING CURRENTS.

(PART 2.)

## EXAMINATION QUESTIONS.

(1) (*a*) How is a squirrel-cage induction-motor armature constructed? (*b*) Explain how the currents are set up in such an armature.

(2) Why is it necessary to insert a resistance in series with either the armature or field of an induction motor when starting the motor?

(3) (*a*) What is an inductor alternator? (*b*) Does an inductor alternator require any moving wire or collector rings?

(4) How is the winding of a three-phase alternator arranged, i. e., how is the armature wound so as to generate three currents that differ in phase by 120°?

(5) (*a*) What is the difference between a core transformer and a shell transformer? (*b*) Why are the coils of transformers wound in sections and interleaved or else wound one over the other?

(6) If a two-phase rotary converter is supplied with alternating current at a pressure of 350 volts, what will be the pressure on the direct-current side? Ans. 495 volts.

(7) (*a*) How does the speed of an induction motor vary with the load? (*b*) What is meant by the slip of an induction motor?

(8) (*a*) What is meant by the ratio of transformation of a transformer? (*b*) A transformer has 600 turns on its primary and 60 turns on its secondary; if the primary is attached to 2,200-volt mains, what will be the secondary voltage?

Ans. 220 volts.

(9) (*a*) Name the essential parts of an ordinary transformer. (*b*) Does a transformer ever deliver as much power from its secondary as it takes in from the primary? (*c*) What are the three sources of loss of power in a transformer?

(10) An alternator has sixteen poles and runs at a speed of 450 revolutions per minute. What is the frequency of the E. M. F. generated? Explain how you obtain your result.

Ans. 60 cycles per sec.

(11) Name two things that cause the secondary voltage of a transformer to fall off when the transformer is loaded, and give reasons for their doing so.

(12) A three-phase rotary converter is to supply direct current at 110 volts for lighting purposes; with what alternating E. M. F. must it be supplied?

Ans. 67.3 volts.

(13) Why is an induction motor so called?

(14) What two methods of connecting up the groups of coils on three-phase armatures are in common use? Explain each.

(15) (*a*) What do you understand by the *pitch* of an alternator? (*b*) Why should the breadth of the inside of the armature coils not be much, if any, less than the width of the pole face?

(16) An alternator is to be directly connected to a water-wheel running at 250 revolutions per minute and is to generate current at a frequency of 25 cycles per second; how many poles should the alternator have?

Ans. 12 poles.

(17) (*a*) What is a synchronous motor? (*b*) How does its construction compare with that of an alternator? (*c*) Why will not a single-phase synchronous motor start up of its own accord when it is connected to the line?

(18) A synchronous motor has 10 poles and is operated by a 25-cycle alternator; what speed (R. P. M.) will the motor run at ? Ans. 300 R. P. M.

(19) Why are open-circuit windings largely used for alternator armatures ?

(20) Will changing the field strength of a synchronous motor alter the speed of the machine, and if not, why ?

(21) How is it that a synchronous motor can take current from the line in proportion to its load without changing its speed ?

(22) (*a*) What is a monocyclic alternator ? (*b*) For what kind of work is the monocyclic alternator used ? (*c*) If the pressure between the outside rings of a monocyclic alternator is 2,200 volts, what will be the pressure between the middle ring and each of the outside rings ?

Ans. (*c*) 1,232 volts.

(23) How is the winding on an alternator arranged so that the machine will deliver two currents that differ in phase by 90° ?

(24) (*a*) For what is the rectifier or commutator used on compound-wound alternators ? (*b*) Does the rectifier change the direction of the current in the lines leading from the alternator, and if not, why ?

(25) If a three-phase rotary converter is supplied with alternating current at 200 volts, what will be the pressure on the direct-current side ? Ans. 326.8 volts.

# ELECTRIC TRANSMISSION.

## (PART 1.)

## EXAMINATION QUESTIONS.

(1) (*a*) What is an ampere-hour meter? (*b*) Would an ampere-hour meter give an accurate indication of the actual power supplied to an induction motor, and if not, why?

(2) Why should transformers operated on constant-potential circuits be protected by primary fuses?

(3) (*a*) Draw a diagram showing how you would connect up an indicating wattmeter to measure the watts supplied to a direct-current motor. (*b*) What precaution must be taken in connecting up a wattmeter?

(4) Power is to be delivered over a line the total length of which (both ways) is 5 miles; 100 horsepower is to be delivered at the end of the line and the pressure at the distant end is to be 500 volts when the 100 horsepower is being delivered. The drop in the line must not exceed 50 volts under full load. Calculate the cross-section of the line wire and give your result in circular mils.

Ans. 850,800 circular mils, approximately.

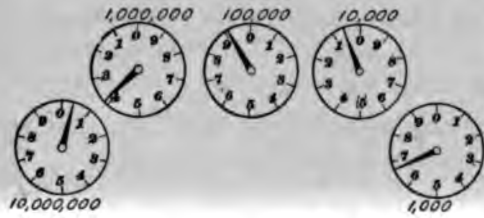
(5) The reading of a customer's meter at the end of a month was 9,995,400, and at the end of the next month it was 230,200. If the constant of the meter were 2 and if the customer were charged 5 cents per kilowatt-hour for power, what would be his bill? Ans. $23.48.

(6) 30,000 watts are delivered over a direct-current transmission line, and when the line is carrying this load the pressure at the end where the power is delivered is 500 volts. (*a*) What is the current in the line? (*b*) If the voltage at the station at the time this load is being delivered is 525 volts, what is the drop in the line? (*c*) How many horsepower are lost in the line? (*d*) How many horsepower are supplied to the line at the power station?

Ans.
(*a*) 60 amperes.
(*b*) 25 volts.
(*c*) 2.01 H. P.
(*d*) 42.2 H. P.

(7) (*a*) What does the meter dial shown in the figure read (to the nearest hundred) and explain how you obtain the reading? (*b*) If the previous meter reading were 300,400 and the constant of the meter ½, how many watt-hours has the customer used since the last reading?

Ans.
(*a*) 390,700.
(*b*) 45,150.



(8) (*a*) Under what circumstances is direct current generally used for electric-power transmission? (*b*) When is alternating current used?

(9) (*a*) If the armature circuit of a Thomson recording wattmeter becomes broken, how is the operation of the meter affected? (*b*) What happens if the resistance in series with the armature becomes short-circuited? (*c*) Can an induction wattmeter be run on a direct-current circuit, and if not, why?

(10) A Thomson meter was tested by running it on a load of lamps and noting the revolutions made by the disk

in a given time. The watts, as calculated by formula **20**, were 630, and the watts indicated by the standard wattmeter, or ammeter and voltmeter, were 650. (*a*) What percentage too slow was the meter? (*b*) How could the trouble be remedied?

(11) The total length of a line of copper wire is 3 miles and the area of cross-section of the wire is 26,000 circular mils. What is the resistance of the line?

Ans. 6.58 ohms, nearly.

(12) (*a*) Make a sketch showing how you would connect three transformers on a three-phase system with both their primaries and secondaries connected $\Delta$. (*b*) If the primary voltage were 1,100 and if the transformers were wound for a ratio of 10 to 1, what pressure would be obtained between the secondary mains? Ans. (*b*) 110 volts.

(13) (*a*) What is meant by the "drop" in a transmission line? (*b*) On what quantities does the "drop" depend in an ordinary direct-current transmission line?

(14) 500 kilowatts are to be delivered over a line 10 miles long (one way) to a load consisting of motors and lights. The three-phase system (60 cycles) is to be used and the loss in the line is to be limited to 10 per cent. of the power delivered, and the voltage at the end of the line is to be 10,000. Calculate (*a*) the full-load current in each line; (*b*) the size of line wire in circular mils and the nearest size B. & S.; (*c*) the volts drop in the line.

Ans. {
(*a*) 33.95 amperes.
(*b*) 39,600 circular mils, or No. 4 B. & S.
(*c*) 1,000 volts.

(15) A wire is .016 inch in diameter; what is its area of cross-section in circular mils? Ans. 256 circular mils.

(16) (*a*) What is an indicating wattmeter? (*b*) What is a recording wattmeter? (*c*) What does a recording wattmeter register?

(17) Name some of the advantages of alternating currents that render them well suited for the transmission of power over long distances at high pressures.

(18) A Thomson recording wattmeter when tested made 15 revolutions of the disk in 1 minute and 20 seconds. If the constant of the meter was 2, what was the average number of watts being expended in the circuit ?

Ans. 1,350 watts.

(19) (*a*) What is a mil ? (*b*) What is a circular mil ?

(20) The power factor of a 500-volt three-phase induction motor is .80, and at full load the motor takes 25 horsepower from the line. What will be the full-load current in each line ? Ans. 26.9 amperes.

(21) (*a*) Why is single-phase alternating current not used to any great extent for power-transmission work ? (*b*) For what class of work is it used ?

(22) Do alternating-current lines have a greater self-induction when they are strung wide apart than when strung close together, and if so, why ?

(23) Would it be practicable to connect two transformers on a two-phase system with their primaries connected across the two different phases and their secondaries in parallel with each other, and if not, why ?

(24) Why are two-phase or three-phase systems used when power is to be transmitted by means of alternating current ?

(25) Why is direct current not suited for the transmission of power over long distances ?

(26) (*a*) Make a sketch showing how you would connect two transformers on a three-phase system. (*b*) Is this arrangement as good as the one using three transformers, and if not, why ? (*c*) If you had to install three transformers to operate a 50-horsepower motor on a three-phase system, what capacity of transformers would you use ?

(27) If it takes a No. 0000 wire to transmit 20 horsepower over a given distance with a drop of 10 per cent. of the terminal pressure of 200 volts, what size wire would it take to transmit the same amount of power over the same distance with the same percentage loss if a terminal pressure of 400 volts were used? Ans. No. 3 B. & S.

(28) Why is it generally not advisable to operate a number of small transformers in parallel?

(29) What advantage has the three-wire direct-current system over the two-wire system?

(30) (*a*) What style of conductor is generally used for ordinary overhead transmission lines using moderate pressures? (*b*) What style of conductor is used for underground work?

(31) (*a*) Make a sketch showing how you would connect two transformers on a single-phase system so as to feed three-wire secondary mains. (*b*) How would you test the secondary mains to see if you had made the right connections?

(32) (*a*) Make a sketch showing how you would connect two transformers with their primary coils in parallel across the mains and their secondaries also in parallel. (*b*) Name some of the precautions that should be taken when connecting transformers in this way.

# ELECTRIC TRANSMISSION.

(PART 2.)

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## EXAMINATION QUESTIONS.

(1) (*a*) What cross-section per ampere should be allowed for the + and the − leads running from a dynamo to the switchboard? (*b*) What cross-section per ampere should be allowed for the equalizer?

(2) (*a*) About what is the minimum size of pole top that should be allowed in good construction? (*b*) About how many poles should be used per mile?

(3) Name some of the advantages and disadvantages of porcelain insulators as compared with glass insulators.

(4) What style of insulator is commonly used for ordinary work using moderate pressures?

(5) What are some of the distinguishing features of the Edison underground-tube system?

(6) Why is it usually desirable to have manholes ventilated?

(7) What conditions must be attained before two alternators can be thrown in parallel?

(8) The insulation resistance of an electric-light system was measured by means of a voltmeter having a resistance of 17,000 ohms. When connected across the circuit, the voltmeter read 120 volts, but when connected between one line and the ground, it indicated 5 volts. What was the insulation resistance of the system? Ans. 391,000 ohms.

(9) Suppose power is supplied on the three-phase system over a three-wire underground cable 12,000 feet long. A ground develops on one of the wires and the Varley loop test is applied to locate the ground, one of the other wires being used as a good wire to make the necessary connections. One end of the battery was grounded as in Fig. 38, and the bridge was balanced with $m = 10$ ohms; $n = 1,000$ ohms; and $p = 162$ ohms. Where was the ground if the resistance of each wire in the cable was .123 ohm per 1,000 feet?

Ans. 10,724 ft.

(10) How could you find out whether two alternators were in synchronism or not?

(11) How would you locate a partial ground on a wire in case a good wire were not available to aid in carrying out the test?

(12) (*a*) Should lightning arresters be installed in the station only, or should they be placed at intervals along the line? (*b*) Does a lightning arrester arrest the discharge; if not, what does it do?

(13) Why must lightning arresters be provided with an arrangement of some kind to suppress arcing?

(14) Can alternators be run in series, and if so, under what conditions?

(15) (*a*) Can two compound-wound dynamos be run in parallel? (*b*) Is an equalizing connection necessary, and if so, what points should it connect?

(16) (*a*) Can compound-wound dynamos be run in multiple with shunt-wound dynamos? (*b*) If it were necessary to run machines in this way, what would you do?

(17) Why will a lightning discharge leap across an air gap in preference to passing through an inductive path?

(18) For what are kicking coils, or reactance coils, used in connection with lightning arresters?

(19) Can two compound-wound machines be made to divide the load properly between them by varying the

shunts across their series coils, and if not, how can they be made to divide the load in the proper proportion ?

(20) If two compound-wound dynamos of unequal capacity are to be run in parallel, what relation must exist between the combined resistance of their series coils and connections to the bus-bar ?

(21) Will shunt-wound dynamos operate well in parallel, and if so, why ?

(22) (*a*) Why are two plain series dynamos, run in parallel, unstable in operation ? (*b*) How can the unstable condition be remedied in large measure ?

(23) (*a*) About what voltage is required per cell for charging a storage battery ? (*b*) What voltage is obtained per cell on discharge ? (*c*) Below what voltage should cells not be discharged ?

(24) Does a storage cell store up electricity ? If not, what does it do ?

(25) (*a*) How is the capacity of a storage battery usually expressed ? (*b*) If a battery is discharged at a high rate, will its total output be diminished ?

(26) (*a*) How is the true efficiency of a storage battery obtained ? (*b*) What is the ampere-hour efficiency ? (*c*) Why is the watt-hour efficiency always less than the ampere-hour efficiency ?

(27) When a storage cell is charged, what is formed on (*a*) the positive plate ? (*b*) the negative plate ? (*c*) What changes do these substances undergo when the cell is discharged ?

(28) What is meant by the positive plate of an ordinary storage cell ?

(29) What is the difference between a Planté type, or formed storage cell, plate, and a Faure, or pasted, plate ?

# A KEY

TO ALL THE

# QUESTIONS AND EXAMPLES

CONTAINED IN THE

# EXAMINATION QUESTIONS

INCLUDED IN THIS VOLUME.

The Keys that follow have been divided into sections corresponding to the Examination Questions to which they refer, and have been given corresponding section numbers. The answers and solutions have been numbered to correspond with the questions. When the answer to a question involves a repetition of statements given in the Instruction Paper, the reader has been referred to a numbered article, the reading of which will enable him to answer the question himself.

To be of the greatest benefit, the Keys should be used sparingly. They should be used much in the same manner as a pupil would go to a teacher for instruction with regard to answering some example he was unable to solve. If used in this manner, the Keys will be of great help and assistance to the student, and will be a source of encouragement to him in studying the various papers composing the Course.

# OPERATION OF DYNAMOS AND MOTORS.

(1) The dust from coal and from the machines mentioned is very injurious to the bearings of engines and electrical machines and also to the commutators and general insulation of the latter. See Art. **1.**

(2) (*a*) Copper brushes are generally used on electric-light dynamos where the current output is large and the voltage low.

(*b*) They are generally set tangential, or approximately so, never radially.

(3) (*a*) Copper brushes are trimmed to fit the commutator by shaping and filing them in an iron jig, properly shaped to fit the surface of the commutator.

(*b*) Carbon brushes are usually made to fit the commutator by putting the brush in position and then drawing a piece of sandpaper (never emery paper) between the brush and the commutator against which the brush-holder spring presses the brush, the sanded side of course being next to the carbon brush.

(4) The odor of hot oil around a machine usually indicates an abnormally hot bearing.

(5) It may be due to the lack of power on the line or an open or short circuit in the field of the machine or in the

connections between the circuit and the motor. See Art. **58.**

(6) Sparking at the brushes may be due to any one of the following causes: too much load, brushes improperly set, commutator rough or eccentric, high or low commutator bars, poor contact between brushes and commutator, dirty brushes or commutator, speed too high, sprung armature shaft, armature too low because of worn bearings, worn commutator, short or open-circuited or reversed armature coil, brushes of too high resistance, a shaky foundation that allows the machine to vibrate excessively, a slipping belt.

(7) The bar-to-bar test is probably the most convenient one, all things being considered. See Arts. **97** to **99,** inclusive.

(8) By connecting a voltmeter across each of the coils in succession. The coil across which a deflection is obtained is the open-circuited coil. In the absence of a voltmeter, incandescent lamps may be used. For example, in Fig. 24 a deflection will be obtained between *c* and *b*, but none between *b* and *a*. See Art. **92.**

(9) Oil is apt to saturate the insulating material between the bars and to become charred, while the emery will collect between the bars. The charred oil and emery are more or less of a conductor, hence the insulation between the bars becomes lower. Emery generally contains iron impurities that make it a conductor. Small pieces of emery may also become lodged in the brushes and scratch the commutator. See Art. **10.**

(10) Carbon brushes have a comparatively high resistance, hence the current in the coils that are short-circuited by the brushes at or near the neutral points is not so great as to produce excessive sparking, even when the brushes due to a momentary change in the load are not in the best, or neutral, position.

(11) (*a*) High bars can usually be filed, sandpapered, or turned down to the surface of the other bars.

(*b*) To remedy a low bar it is usually necessary to turn down, file, or sandpaper the whole commutator to a smooth and true surface.

(12) The commutator becomes rough, the brushes heat and spark, the belt squeaks, and the machine grows hot all over.

(13) Severe sparking is caused and the circuit-breaker opened because the motor armature generates but little counter E. M. F., and forms practically a short circuit across the supply mains. In some cases the motor may speed up excessively.

(14) A rotary converter may be started by connecting the alternating-current side to the line; by supplying the direct-current side with direct current from another rotary or from a storage battery; by starting up the alternator. See Art. **89.**

(15) The other coils become warm. See Art. **41.**

(16) By holding a piece of iron near the armature; the piece of iron will vibrate when the coil passes it. See Art. **23.** Another method is to use the device described in Art. **97.**

(17) (*a*) An unusually large deflection would indicate an open circuit in the armature coil whose terminals are supposed to be connected to the commutator bars upon which the testing clips rest.

(*b*) No deflection would indicate one of three things: either a dead cross in the coil connected to the commutator bars upon which the testing clips rest, or a cross between the two bars themselves, or that there was an open circuit in the same half of the armature in which the testing clips were being used, but somewhere else except between the test clips. A smaller deflection than that given by a good coil would indicate a partially short-circuited coil or poor insulation between the turns or between the commutator bars under the test clips.

(18) (*a*) If the pressure is greater than necessary, the wear on the commutator and the friction to be overcome will be unnecessarily great.

(*b*) If the pressure is too small, there will be sparking and heating because of the bad contact between brush and commutator.

(19) (*a*) Such scratches usually indicate that there are particles of hard foreign matter under one or more of the brushes.

(*b*) The remedy is to remove the brushes and clean them thoroughly.

(20) The brushes will play or bear over the whole wearing surface of the commutator, thus preventing the wearing of the commutator in ruts.

(21) It would indicate that the bearings had worn down or that a field core had become loose, thus allowing the armature to rub against the core or pole piece.

(22) (*a*) In a dynamo, one field coil reversed would reduce the voltage and perhaps render the machine incapable of generating at all.

(*b*) In a motor, one field coil reversed would increase the current required to start the motor, would abnormally increase the speed after it is started, and would cause the brushes to spark. A motor with but two field coils may refuse to start or else start very slowly if one of its field coils is reversed.

(23) All residual magnetism may have disappeared or the field and armature may be improperly connected together. Reversing either the armature or the field, not both, after they were once properly connected, would destroy whatever residual magnetism there may have been and, consequently, the machine would refuse to generate. For other causes and remedies see Arts. **49** to **52,** inclusive.

(24) Ordinary synchronous motors will not start up by themselves under load. They must be brought up to synchronism under no load, either by themselves, by switching on the line current, or by some outside source of power, as, for example, by a small induction motor.

(25) It would indicate that the one armature coil was short-circuited.

(26) A broad scratch around the surface of a commutator indicates that probably one of the brush holders has been set too close or has become loose and slipped down, so that it touches the commutator.

(27) An induction motor is started up by first seeing that the starting compensator, resistance, or other device is in circuit, then throwing in the main switch and cutting out the compensator or resistance as the motor comes up to speed.

# DYNAMO-ELECTRIC MACHINERY.

(1) This relation is expressed by the formula $E = E_m + C R_a$; that is, the E. M. F. supplied at the brushes is equal to the counter E. M. F. generated in the motor armature plus the E. M. F. required to force the current through the armature against its resistance. This last quantity, $C R_a$, called the drop or fall of potential through the armature, is equal to the product of the current $C$ and the resistance of the armature $R_a$.

(2) Because if the external resistance is increased, the current will decrease; this will weaken the field, since the field and armature are directly in series, and, hence, lower the E. M. F. generated by the armature, which still further decreases the current. If the external resistance is decreased, the current and E. M. F. will each be increased.

(3) When the current increases beyond a certain strength, a regulating magnet, connected directly in the main circuit, draws up its cores, thereby opening a short, or shunt, circuit around quite a powerful regulating magnet. This allows the regulating magnet, which is now supplied with current from the main circuit, to attract its keeper, thereby separating, by means of a system of levers, the two brushes of each set. This separating of the brushes of each set short-circuits the armature for a very brief interval of time. The more the brushes are

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separated the longer is the armature short-circuited. In any case, however, this interval is extremely short, although it may occur as often as 5,100 times per minute. The great self-induction of the field and armature prevents the fall of the current to zero each time the armature is short-circuited. As the current tends to increase the greater becomes the length of the short-circuiting intervals and, hence, the average value of the current remains approximately constant. See Arts. **21** and **22.**

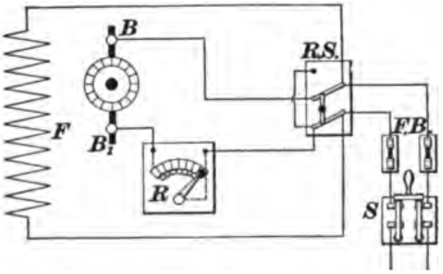
(4) (*a*) The length of the arm of the brake being 36 inches, or 3 feet, the torque of the motor is 27 × 3 = 81 pound-feet. Arts. **33, 34,** and **35.** The revolutions per minute being 900, the horsepower output of the motor is, from formula **2,**

$$\text{H. P.} = \frac{2 \times 3.1416\, T S}{33{,}000} = \frac{6.2832 \times 81 \times 900}{33{,}000} = 13.88 \text{ H. P.}$$

Ans.

(*b*) To find the efficiency, it is first necessary to find the input and reduce the input and the output to the same units. Art. **35.** In this case the input is 25 × 480 = 12,000 watts. Reducing 13.88 horsepower to watts, 13.88 × 746 = 10,354 watts. Then, the efficiency **E** $= \frac{100 \times 10{,}354}{12{,}000} = 86.3$ per cent. Ans.

(5) The connections would be about as shown in the figure, in which *F* is the field circuit, *B*, $B_1$ the brushes of the motor, *R* the starting resistance, *R S* the reversing switch, *F B* the fuse boxes, and *S* the main switch.



(6) The speed of a direct-current shunt-wound motor may be varied by changing the field strength or by changing the E. M. F. applied to the armature by inserting an adjustable resistance in the armature circuit.

(7) Because the self-induction of the coil having the lesser E. M. F. prevents the flow of current. Art. **14.**

(8) The speed of a direct-current series-wound motor may be varied by varying the strength of the field, by altering the effective number of turns in the field coils, or by inserting an adjustable resistance in the circuit in series with the motor.

(9) (*a*) See Art. **3.**

(*b*) See Art. **5.**

(10) The input to the motor being $33 \times 230 = 7,590$ watts, and the efficiency being 85 per cent., the output is $\frac{7,590 \times 85}{100} = 6,451.5$ watts. This is equal to $\frac{6,451.5}{746} = 8.65$ horsepower. The arm of the brake being 2 feet long and the pressure on the scale platform being 20 pounds, the torque of the motor must be 40 foot-pounds $= T$. Knowing the horsepower and the torque, the speed may be found from formula **3**, $S = \frac{33,000 \times \text{H. P.}}{2 \times 3.1416\ T}$. Substituting the above values for H. P. and $T$, $S = \frac{33,000 \times 8.65}{2 \times 3.1416 \times 40} = \frac{285,450}{251.328} = 1,136$ rev. per min. Ans.

(11) If the starting resistance were in series with the whole shunt-wound motor instead of in series with the armature only, there would be on starting the motor only a small current through the field coils and, consequently, the field would be so weak that an excessively large current would be required in the armature to furnish the necessary torque for starting.

(12) Because as the coil moves across the center of a pole piece, as many lines of force pass out across one side of the coil as pass in across the other side of the coil; that is, there is no change in the actual number of lines of force that pass through the coil. Or, we may consider that since one side of the coil is cutting lines of force just as fast and in the same direction as the other side, hence the E. M. F.'s

generated in each side are exactly equal and opposite, and hence there is no resultant E. M. F. or current generated in the coil. See, also, Art. **17.**

(13) It is a pulsating current; that is, the current flows always in one direction in the line circuit, but it fluctuates rapidly (many times a second) in strength. When such a current is referred to as a constant current, it is meant that the average strength of the current is constant. See Art. **12.**

(14) A parallel- or lap-wound drum armature must be provided with as many sets of brushes as there are poles on the machine.

(15) A series- or wave-wound drum armature need be provided with only two sets of brushes. However, any number of sets, not exceeding the number of poles on the machine, may be used, and it is preferable, especially on large generators, to use as many sets of brushes as there are poles.

(16) The maximum E. M. F. that the constant-current dynamo is capable of generating limits its output. See Art. **23.**

(17) When in the position of least action, a coil is momentarily disconnected from the external circuit, then thrown in parallel with the coil ahead of it, then in series with the other two coils that are then in parallel, then in parallel with the coil behind it, and then disconnected from the circuit again. See Art. **20,** also Fig. 7.

(18) (*a*) Of the 5 amperes input, by Ohm's law, $\frac{125}{62.5} = 2$ amperes go to the field, the loss being, therefore, $2 \times 125 = 250$ watts. The rest, or $3 \times 125 = 375$ watts, make up the friction and core losses of the machine. Art. **37.** When taking an input of 77 amperes at 125 volts, or 9,625 watts, there would still be required 250 watts for the field and 375 watts for the core losses and friction. Of the 77 amperes, 75 flow through the armature, and as this has

a resistance of .04 ohm, the armature $C^2 r$ would be $75^2 \times .04 = 225$ watts. The total losses would then be $250 + 375 + 225 = 850$ watts, and the output would therefore be $9{,}625 - 850 = 8{,}775$ watts, or $\frac{8{,}775}{746} = 11.76$ H. P. Ans.

(*b*) The output being 8,775 watts and the input 9,625, the efficiency is $\frac{100 \times 8{,}775}{9{,}625} = 91.17$ per cent. Ans.

(19) The E. M. F. of the Excelsior constant-current dynamo is regulated by a controlling magnet that causes current to flow through a small motor in one direction as the current increases, and in the opposite direction as the current decreases. When the small motor revolves in one direction, due to an increasing current, it not only shifts the brushes from the neutral point, but it also cuts out some of the turns of the field coil. These two changes reduce the E. M. F. generated in the armature and, hence, keep the current from increasing beyond its proper constant value. When the small motor revolves in the opposite direction, due to a decreasing current, the operations mentioned are reversed and, hence, the current is kept from decreasing below its proper constant value. See Art. **10.**

(20) The current flowing in an armature conductor in a parallel- or lap-wound armature is equal to the total armature current divided by the number of poles, hence the current in this case would be one-sixth of the total current.

(21) To reverse the direction of rotation of a motor, the direction of the current must be reversed either through the field coils or through the armature; the current must not be reversed in both the field and armature. Hence, to reverse the direction of rotation of the motor reverse the connections with respect to the external circuit of either the field or armature terminals.

(22) The output of a constant-potential motor is limited by the heating of the armature and field and the sparking between the brushes and commutator. See Art. **37.**

(23) See Art. **33.**

(24) The E. M. F. supplied to the terminals of a motor may be varied by inserting an adjustable resistance or rheostat in the line circuit or by varying the E. M. F. of the generator from which the current is obtained. The E. M. F. at the brushes of a shunt-wound motor may be varied without varying the strength of the field by connecting the adjustable resistance only in the path of the current supplied to the armature, the field coils being connected directly to the line wires and not through the adjustable resistance first.

(25) (*a*) No.

(*b*) Half the total current output flows in each armature conductor, since there are but two parallel paths for the current through the armature winding no matter how many pairs of brushes may be used.

(26) (*a*) See Art. **38.**
(*b*) See Art. **38.**

(27) See Art. **6.**

(28) (*a*) A parallel winding is most suitable because there are as many paths in parallel as there are poles, and hence each conductor has to carry only a part of the total current.

(*b*) A series winding is most suitable, because a large number of conductors connected in series are required in order to give the high voltage, and although each conductor must carry half the total current output, still the latter is comparatively small where the voltage is high.

(29) See Art. **42.**

# ALTERNATING CURRENTS.

(PART 1.)

(1) (*a*) A cycle is the complete set of values that an alternating current or E. M. F. passes through repeatedly.

(*b*) An alternation is the set of values represented by a half wave or half cycle. See Art. **9.**

(2) (*a*) The frequency is the number of complete cycles passed through in a given interval of time. The interval of time used is generally the second, so that the frequency may be defined as the number of cycles that the current passes through per second.

(*b*) A 60-cycle alternating-current dynamo is one that generates an E. M. F. that passes through 60 cycles per second. See Art. **8.**

(3) A direct current always flows in the same direction, whereas an alternating current is continually reversing its direction of flow.

(4) 15,000 alternations per minute are equal to 7,500 cycles per minute, because each alternation is half a cycle. 7,500 cycles per minute are equal to 125 cycles per second. Ans.

(5) (*a*) Two alternating currents or E. M. F.'s of the same frequency are said to be in phase when they come to their maximum values at the same instant. See Fig. 7, Art. **10.**

(*b*) They are out of phase when they do not come to their maximum values at the same instant. In order for there to be a difference of phase, we must always have under consideration at least two currents, two E. M. F.'s, or one current and an E. M. F.; that is, two or more currents may differ from each other in phase, or two or more E. M. F.'s may differ in phase, or we may have a phase difference between currents and E. M. F.'s. See Art. **11.**

(6) (*a*) Yes. See Art. **13.**

(*b*) Since the currents are in phase, the total current furnished by the alternator will be the sum of the three separate currents, i. e., 10 + 20 + 25 = 55 amperes.

(7) It means that the E. M. F. of the second is brought to the same frequency as that of the first machine, and also that its E. M. F. is brought into phase, or into step, with the E. M. F. of the first machine. See Art. **12.**

(8) The total current furnished by the alternator will not be 20 amperes, but will be some amount less than 20 amperes, depending on how much the currents of 8 and 12 amperes differ in phase. Since the two currents are not in phase, there are intervals when they oppose each other, and, consequently, the resultant current is less than their sum. It is evident that if the currents were exactly opposite in phase, the total current would be but 12 − 8 = 4 amperes. See Art. **14.**

(9) Since one whole cycle is represented by 360°, a phase difference of 60° would mean one-sixth of a complete cycle. See Art. **16.**

(10) When they differ in phase by 90°, or one-quarter of a complete cycle. See Art. **17.**

(11) (*a*) A two-phase system is one that makes use of two simple alternating currents that differ in phase by 90°, or one-fourth of a complete cycle.

(*b*) A three-phase system is one that makes use of three simple alternating currents that differ in phase by 120°, or one-third of a cycle. See Art. **20.**

(12) (*a*) From Art. **19** we see that the current in the middle wire is 1.414 times the current in the outside wires; hence the current in the middle wire = 200 × 1.414 = 282.8. Ans.

(*b*) Also the voltage between the outside lines is 1.414 times the voltage on each phase, hence the voltage between the outside lines = 1,100 × 1.414 = 1,555.4 volts. Ans.

(13) Because the sum of the three currents is at all instants equal to zero; i. e., one current is always equal and opposite to the sum of the other two, thus making the resultant current zero and rendering a fourth return wire unnecessary. Each wire acts alternately to carry the return current for the other two.

(14) It is shown in Art. **21** that in a balanced three-phase system the current flowing in one wire is equal to the sum of the currents flowing in the other two and is in the opposite direction. Also, that when the current in one wire is at its maximum value, the currents in the other two are one-half as large and in the opposite direction. It follows, then, that if the current in one wire is at its maximum value of 100 amperes and is flowing *out*, the currents in the other two wires must be 50 amperes and flowing *in*.

(15) (*a*) The maximum value is the highest value reached during each half wave or alternation.

(*b*) The average value is the average of all the values of current or E. M. F. that are passed through during a half cycle.

(*c*) The average value is .636 times the maximum value, or a little less than two-thirds the maximum. See Art. **24.**

(16) (*a*) The effective value of an alternating current is that value that will produce the same heating effect in the circuit as a continuous current of the same amount. The effective value is often called the square-root-of-mean-square value, because it is equal to the square root of the average of the squares of the values of the current at each instant throughout a cycle.

(*b*) The effective value is .707 times the maximum, or slightly more than seven-tenths of the maximum. See Art. **24.**

(17) (*a*) It means that the effective or square-root-of-mean-square value is 50 amperes and that the alternating current produces the same heating effect as would 50 amperes direct current.

(*b*) Since the effective value (50 amperes) is .707 times the maximum, the maximum value in this case must be $\frac{50}{.707} = 70.7$ amperes, and the current will alternate between the values $+70.7$ amperes and $-70.7$ amperes.

(*c*) The average value is .636 times the maximum, or $.636 \times 70.7 = 45$ amperes, approximately, or we may get the same result by dividing the effective value (50 amperes) by 1.11, i. e., $\frac{50}{1.11} = 45$, approximately. See Art. **25.**

(18) (*a*) The E. M. F. of self-induction is set up in a coil or circuit by reason of the changing magnetic field threading the coil or circuit, this changing field being set up by a changing current flowing in the coil, circuit, or whatever electrical device is under consideration.

(*b*) No, because the current is steady and, hence, no changing field can be set up to induce the E. M. F. In order that an E. M. F. may be set up, the magnetic field and the coil or circuit must be continually changing relatively to each other. See Arts. **27** and **28.**

(19) (*a*) The coefficient of self-induction of any electrical circuit or device is a quantity that is a measure of the ability that the circuit or device has for setting up lines of force through itself when a current is sent through it. If the coefficient of self-induction is high, it means that a small current is capable of setting up a large number of lines of force, and *vice versa*. The coefficient of self-induction is defined in Art. **30**; it is equal to the number of lines threading the circuit or coil, when a current of 1 ampere is flowing, multiplied by the number of turns and divided by $10^8$.

(*b*) The henry is the unit used to express inductance.

(*c*) Yes, because the coil when wound on the iron core would be able to set up a much larger magnetic flux through itself than when wound on a wooden core.

(20) It makes the current lag behind the E. M. F., so that the current does not reach its maximum value until after the E. M. F. has passed its maximum value. See Art. **26.**

(21) (*a*) The induced E. M. F. is at right angles to the current, and when the current is a maximum the induced E. M. F. is passing through zero, and *vice versa*. Also, the induced E. M. F., or E. M. F. of self-induction, is 90° *behind* the current in phase.

(*b*) The E. M. F. *to overcome* self-induction is the equal and opposite of the E. M. F. of self-induction; hence, it is 90° *ahead* of the current in phase. See Art. **33.**

(22) From formula **2,** we have: Induced E. M. F. $= 6.283\, n\, L\, C = 6.283 \times 60 \times .02 \times 5 = 37.7$ volts, nearly. Ans.

(23) From Art. **35** and Fig. 25 we see that the applied E. M. F. is equal to the square root of the sum of the squares of the induced E. M. F. and the E. M. F. necessary to overcome resistance, because in Fig. 25, $o\,c =$ applied E. M. F. and $o\,c^2 = o\,b^2 + b\,c^2$, or

$$o\,c = \sqrt{o\,b^2 + b\,c^2}.$$

In this case $o\,b$ is 8 volts and $b\,c$ is 20 volts; hence,

Applied E. M. F. $= \sqrt{8^2 + 20^2} = \sqrt{464} = 21.54$ volts. Ans.

(24) (*a*) The reactance of a circuit is that quantity which multiplied by the current gives the E. M. F. necessary to force the current against the self-induction of the circuit.

(*b*) The value of the reactance is given by the product $6.283\, n\, L$, where $n$ is the frequency in cycles per second and $L$ the coefficient of self-induction.

(*c*) Reactance, like resistance, is expressed in ohms. See Art. **38.**

(25) (*a*) The impedance of a circuit is that quantity by which the current must be multiplied to give the applied, or impressed, E. M. F. necessary to force the current through the circuit.

(*b*) The impedance is equal to the square root of the sum of the squares of the resistance and reactance; i. e., $\sqrt{R^2 + (6.283\,n\,L)^2}$.

(*c*) Impedance, like resistance and reactance, is expressed in ohms. See Art. **39.**

(26) $C = \dfrac{E}{\sqrt{R^2 + (6.283\,n\,L)^2}}$, or current $= \dfrac{\text{applied E. M. F.}}{\text{impedance}}$. See Art. **36.**

(27) (*a*) The reactance is equal to $6.283\,n\,L = 6.283 \times 60 \times .1 = 37.7$ ohms, nearly. Ans.

(*b*) Impedance $= \sqrt{\text{resistance}^2 + \text{reactance}^2} = \sqrt{20^2 + 37.7^2} = \sqrt{1821.3} = 42.7$ ohms, approximately. Ans.

(*c*) The current $= \dfrac{\text{applied E. M. F.}}{\text{impedance}} = \dfrac{1{,}000}{42.7} = 23.4$ amperes. Ans.

(*d*) If the circuit had no self-induction, the reactance would become zero (see Art. **36**); hence, we would have

$$\text{Current} = \frac{E}{\sqrt{R^2}} = \frac{1{,}000}{20} = 50 \text{ amperes. Ans.}$$

It is thus seen that with the given applied E. M. F. of 1,000 volts, the effect of the self-induction is to cut down the current from 50 amperes to 23.4 amperes.

(28) It has exactly the opposite effect to self-induction; i. e., it makes the current lead the E. M. F. instead of lag behind it.

(29) The power expended in watts cannot be obtained under such circumstances because the current and E. M. F. are not in phase and there are intervals during each cycle when the current and E. M. F. are opposing each other, so

that the actual power in watts is less than would be found by multiplying the volts by the amperes. See Art. **49.**

(30) (*a*) The power factor is the quantity by which the volt-amperes or apparent watts must be multiplied to give the number of actual watts expended. Or it may be defined as the ratio of the actual watts or true watts to the apparent watts.

(*b*) The value of the power factor for direct-current circuits or for non-inductive, alternating-current circuits, is 1. See Arts. **50** and **51.**

(31) Apparent watts $= 50 \times 100 = 5{,}000$; power factor $= \frac{\text{true watts}}{\text{apparent watts}} = \frac{4{,}200}{5{,}000} = .84$. Ans. See Arts. **50** and **51.**

# ALTERNATING CURRENTS.

## (PART 2.)

(1) (*a*) A squirrel-cage armature consists of a number of copper bars placed in slots arranged around the periphery of a laminated core. These bars are all connected together at each end by means of rings, thus forming the bars into a number of closed circuits. See Fig. 29.

(*b*) The revolving field set up by the field windings cuts across the conductors, thus inducing E. M. F.'s that are able to set up currents because the bars are formed into closed circuits.

(2) To prevent a heavy rush of current in the armature and field. If a heavy rush of current is allowed in the armature it reacts on the field so as to greatly reduce the field strength and bring the starting torque down to a small amount. Besides, the heavy rush of current affects other motors or lights on the system, and is therefore objectionable. See Art. **48.**

(3) (*a*) An inductor alternator is one in which the E. M. F. is set up in stationary armature coils by varying the magnetic flux passing through them by means of revolving masses of iron.

(*b*) No; the magnetic flux can be set up by means of a stationary coil surrounding the inductor, and as the armature coils are also stationary, no moving wire or sliding contacts are required.

(4) The armature is provided with three groups of coils that are displaced relatively to each other on the armature core so that the currents generated in them differ in phase by the required amount. The coils may be displaced a distance equivalent to 120° of the phase difference, i. e., one-third the distance from the center to center of poles of like polarity, or they may be displaced by a distance giving a phase difference of 60°, i. e., one-sixth the distance from the center to center of poles of like polarity. In the latter case, one of the phases is reversed in order to give three currents differing in phase by 120° instead of three differing in phase by 60°. This latter method of winding is very generally used because it is somewhat easier to carry out mechanically than the first. See Art. **18.**

(5) (*a*) In the core transformer the coils are wound around the core, and thus cover the core to a large extent, while in the shell transformer the iron magnetic circuit is arranged so that it covers the larger part of the coils. See Figs. 21, 22, 23, and 24.

(*b*) In order to avoid magnetic leakage. If the coils are interleaved, there is not the chance for magnetic flux to leak between them that there is when they are separated. See Arts. **30** and **31.**

(6) The relation between the voltage of each phase and the direct-current voltage is the same for the two-phase converter as for the single-phase. See Art. **52.** Applying formula **3,** we have

$$E = .707\ V;$$
$$350 = .707\ V;$$

or $V = \frac{350}{.707} = 495$ volts. Ans.

(7) (*a*) The speed falls off slightly with an increase in load, but the speed regulation as a whole is fully as good as that of a shunt-wound direct-current motor.

(*b*) The slip is the difference in speed between the revolving armature and the revolving field. It is usually expressed as a percentage of the speed at which the motor would run when in synchronism with the alternator. See Art. **47.**

(8) (*a*) The ratio of transformation is the ratio of the primary voltage to the secondary voltage at no load or it is the ratio of the number of primary turns to the number of secondary turns.

(*b*) The ratio of transformation is $\frac{600}{60} = 10$; hence the secondary voltage will be $\frac{2200}{10} = 220$. Ans. See Art. **26.**

(9) (*a*) A transformer consists essentially of three parts, namely, the primary coil or group of coils, the secondary coil or group of coils, and the laminated core. The coils are wound around the core, and the purpose of the core is to carry the magnetic flux (set up by the primary) through the secondary.

(*b*) No; because there is always some loss in the transformer.

(*c*) The copper loss, or loss due to the resistance of the coils; the loss due to eddy currents set up in the iron core; the loss due to hysteresis in the iron caused by the rapid reversals of the magnetism. See Art. **28.**

(10) From formula **1,** we have

$$n = \frac{p}{2} \times s;$$

where $p$ = number of poles and $s$ = revolutions per second, hence

$$n = \frac{16}{2} \times \frac{450}{60} = 60 \text{ cycles per second. Ans.}$$

(11) The resistance of the primary and secondary coils, also magnetic leakage. Part of the E. M. F. is required to overcome the resistance of the coils; the drop in the primary lessens the E. M. F., which divided by the ratio of transformation gives the secondary E. M. F. The effect of the resistance of the secondary is, of course, to cut down the E. M. F. at the terminals of the secondary. The magnetic

leakage lowers the secondary E. M. F. because it reduces the number of lines of force that thread through the secondary. See Art. **27.**

(12) Using formula **4,** we have

$$E = .612\ V;$$
$$E = .612 \times 110 = 67.3 \text{ volts. Ans.}$$

(13) Because the current in the armature is induced by the magnetism set up by the currents in the field instead of being led into the armature from an outside source, as in ordinary motors.

(14) The two methods are the **Y** or star connection and the Δ (delta) or mesh connection. In the former, one end of each group is connected to a common junction and the other three ends are attached to the collector rings. In the Δ method the three groups are connected so as to form a closed circuit, and the collector rings are attached to the junctions of the groups. See Art. **20.**

(15) (*a*) The distance between the centers of the poles.

(*b*) Because there would be danger of opposing E. M. F.'s being set up in the two sides of the coil. See Art. **8.**

(16) The speed $s$ in revolutions per second is $\frac{250}{60}$; hence, applying formula **2,** we have

$$\frac{250}{60} = \frac{2 \times 25}{p}, \text{ or } p = \frac{2 \times 25 \times 60}{250} = 12.$$

$p$ is the number of poles; hence, the number of poles required will be 12. Ans.

(17) (*a*) A synchronous motor is an alternating-current motor that runs in synchronism with the alternator that supplies it with current. See Art. **38.**

(*b*) They are practically the same in construction as the alternator of the same type. Synchronous motors, like alternators, may be built with either a revolving armature or revolving field.

(*c*) Because the armature is subjected to a rapidly reversing torque and the turning effort in one direction is followed by another in the opposite direction before the armature gets started. See Art. **39.**

(18) The speed will be such that $s = \frac{2n}{p}$, when $n$ is the frequency and $p$ the number of poles, or $s = \frac{2 \times 25}{10} = 5$ revolutions per second, or 300 R. P. M. Ans. See Art. **42.**

(19) Because they give a larger number of conductors in series between the collector rings than closed-circuit windings having the same number of armature conductors, and, hence, are well adapted to the generation of the high voltages that are generally required in connection with alternating-current systems. See Art. **5.**

(20) No; because the motor must run at the same frequency as the alternator, and the only thing that can change the speed of the motor is a change in the speed of the alternator driving it. Changing the field excitation of a synchronous motor will, however, change the current that the motor takes when carrying a given load, and the field excitation should always be adjusted so that the motor takes the minimum current.

(21) When the motor is running without load, the E. M. F. of the motor is almost exactly opposite in phase to that of the dynamo, but as the load is applied, the motor lags a small fraction of a revolution, thus displacing its E. M. F. with regard to that of the alternator, so that it is not so nearly opposed to it. This allows more current to flow through the motor and enables it to carry its load. See Art. **40.**

(22) (*a*) A monocyclic alternator is a single-phase machine provided with an auxiliary winding that is displaced 90° from the main winding. This auxiliary winding has about one-quarter as many turns as the main winding and is intended to supply a displaced current for use in

starting motors. One end of the auxiliary winding is connected to the middle point of the main winding and the other end is carried to the middle collector ring.

(*b*) The monocyclic machine is intended for those places where the load consists principally of lights, but where it may be desired to operate a few motors also.

(*c*) The pressure between the middle and outside rings is about .56 times the pressure generated in the main winding, or $.56 \times 2{,}200 = 1{,}232$ volts. Ans.

(23) The armature is provided with two windings or groups of coils that are displaced from each other, so that when the current in one group of coils is at its maximum value, the current in the other group is at zero. See Arts. **17** and **57.**

(24) (*a*) The rectifier is used to make the current that flows through the series field coils always flow in the same direction.

(*b*) No; because the rectifier simply changes the connections of the terminals of the series coil as the current alternates, so that, although the current in the series coils does not reverse, the current in the mains is alternating. See Art. **13.**

(25) From formula **4** we have

$$E = .612\ V;$$

or,

$$200 = .612\ V;$$

and

$$V = 326.8. \quad \text{Ans.}$$

# ELECTRIC TRANSMISSION.

## (PART 1.)

(1) (*a*) An ampere-hour meter is one that gives the average value of the product of the current in amperes by the time in hours during which the current was used.

(*b*) No; because the power factor is not taken into account and the current might be much larger in proportion to the actual watts or power supplied than it would be if the load were non-inductive. See Art. **102.**

(2) Because if a short circuit should occur in the primary or secondary coils, there would be a heavy rush of current and the coils would be burned out if the transformer were not at once disconnected from the circuit. Also, the fuses protect the transformer against overloads. See Art. **71.**

(3) (*a*) The connections would be similar to those shown in Fig. 37.

(*b*) Care should be taken to see that the current coil and pressure coil are not confused, because if the low-resistance current coil were connected across the circuit, a short circuit would result. See Art. **94.**

(4) 100 horsepower $= 100 \times 746 = 74{,}600$ watts,

hence $$\text{Current} = \frac{74{,}600}{500} = 149.2 \text{ amperes.}$$

The length of wire is 5 miles, or $5 \times 5{,}280 = 26{,}400$ feet.

Applying formula **10**, we have

Circular mils $= \frac{10.8 \times 26{,}400 \times 149.2}{50} = 850{,}800$ approximately.

This would call for a stranded cable or about 4 No. 0000 wires in multiple.

(5) It is easily seen from the figures that the meter has run up to its limit (10,000,000) and has started over again. Hence, the watt-hours will be $(10{,}000{,}000 - 9{,}995{,}400)2 + (230{,}200)2 = 469{,}600$ watt-hours, or 469.6 kilowatt-hours. Hence, amount of bill would be

$$469.6 \times .05 = \$23.48. \quad \text{Ans.}$$

(6) (*a*) Since 30,000 watts are delivered and since the pressure at the end of the line is 500, the current must be

$$C = \frac{W}{E} = \frac{30{,}000}{500} = 60 \text{ amperes.} \quad \text{Ans.}$$

(*b*) Since the station voltage is 525 and the voltage at the distant end of the line is 500, the drop or loss in pressure must be equal to $525 - 500 = 25$ volts. Ans.

(*c*) The watts lost in the line will be equal to the current multiplied by the volts drop; hence,

$$\text{Watts lost} = 60 \times 25 = 1{,}500,$$

and since 1 horsepower = 746 watts, we have

$$\text{Horsepower lost in line} = \frac{1{,}500}{746} = 2.01. \quad \text{Ans.}$$

(*d*) The watts supplied must be equal to the watts delivered plus the watts lost; hence, watts delivered to the line $= 30{,}000 + 1{,}500 = 31{,}500$, and the horsepower delivered to the line $= \frac{31{,}500}{746} = 42.2$. Ans.

(7) (*a*) Starting with the dial at the extreme right, we note that the hand is about $\frac{7}{10}$ of the way between 6 and 7; hence, the reading is 670; but 700 would probably be taken, as it is hardly worth while to take the reading closer than

the nearest hundred. The second hand has not completed the division from *0* to *1*, hence we have the reading 0700; the third hand has completed a little over nine divisions, hence we have 90,700. The fourth hand has not completed quite four divisions, and the fifth hand has not completed one division, hence we have the complete reading 390,700.

(*b*) $390,700 - 300,400 = 90,300$; and since the constant is $\frac{1}{2}$, the actual watt-hours will be $90,300 \times \frac{1}{2} = 45,150$. Ans.

(8) (*a*) Direct current is usually employed where the distance of transmission is short or in cases where high pressures are not necessary.

(*b*) Alternating current is used in cases where the power must be transmitted over a considerable distance and where high pressures must be used. Alternating current at low pressure is also used in many short-distance transmissions, as, for example, in factories. See Art. **3.**

(9) (*a*) The meter will not operate even if the magnets are swung in as far as they will go.

(*b*) The meter will run much above its correct speed and there is danger of the armature being burned out.

(*c*) No; because these meters depend on induced currents for their operation, and a continuous current cannot set up the changing magnetic field necessary to induce the currents in the armature of the meter. See Arts. **118** and **101.**

(10) (*a*) $\frac{630}{650} = .969$, or 96.9 per cent. of the actual energy was recorded by the meter; hence the meter was 3.1 per cent. too slow.

(*b*) The trouble could be remedied by shifting the permanent magnets in a little.

(11) By using formula **9,** we can calculate the resistance because both the length and cross-section of the wire are known. In order to use the formula, the length $L$ must be expressed in feet, hence $L = 5,280 \times 3 = 15,840$ feet, and $R = \frac{10.8 \times L}{A} = \frac{10.8 \times 15,840}{26,000}$ or 6.58 ohms, nearly. See Art. **44.**

(12) (*a*) The connections should be similar to those shown in Fig. 31 (*c*).

(*b*) Since both the primary and secondary are connected Δ, the voltage applied to each primary coil will be 1,100, and the voltage between the secondary mains will be $\frac{1100}{10} = 110$ volts. Ans.

(13) (*a*) The "drop" is the loss or falling off in pressure that occurs between the power station and the distant end of the line.

(*b*) The drop depends on the resistance of the line and the amount of current transmitted over the line. The drop in volts is equal to the current in amperes multiplied by the line resistance expressed in ohms. The drop, therefore, increases as the load on the line increases. See Arts. **36** and **37**.

(14) (*a*) To find the full-load current, we will use formula **15.** Since the load consists of motors and lights, and since the three-phase system is to be used, the constant $T$ will be .679. $W = 500{,}000$ watts, because 500 kilowatts are to be transmitted. $E_s = 10{,}000$; hence,

$$\text{Current} = \frac{W}{E_s} \times T = \frac{500{,}000}{10{,}000} \times .679 = 33.95 \text{ amperes. Ans.}$$

(*b*) The size of wire in circular mils may be obtained by using formula **14,**

$$\text{Circular mils} = \frac{D \times W}{P \times E_s^2} \times t.$$

In this case, $D = 10 \text{ miles} = 52{,}800$ feet;
$W = 500{,}000$;
$P = 10$;
$E_s = 10{,}000$;
$t = 1{,}500$.

$$\text{Hence, circular mils} = \frac{52{,}800 \times 500{,}000}{10 \times 100{,}000{,}000} \times 1{,}500 = 39{,}600, \text{ or}$$

about a No. 4 B. & S. Ans.

(*c*) To calculate the drop, we may use formula **16.**

Or,
$$\text{Drop} = \frac{P \times E_2}{100} \times M,$$

where $P = 10$; $E_2 = 10{,}000$; and $M$ for this case is equal to 1.

Hence,
$$\text{Drop} = \frac{10 \times 10{,}000}{100} = 1{,}000 \text{ volts. Ans.}$$

(15) The diameter of the wire is .016 inch, or 16 mils, and since the area of cross-section in circular mils is equal to the square of the diameter expressed in mils, we have area of cross-section in circular mils $= 16^2 = 256$. Ans.

(16) (*a*) An indicating wattmeter is an instrument that indicates the watts expended in a circuit at any given instant. Its reading indicates the actual watts expended at the time the reading is taken; that is, it gives the product of the volts and amperes when used with direct current or with alternating current on a non-inductive circuit. If used on an inductive alternating-current circuit, the indicating wattmeter indicates the actual watts expended or the product of the volt-amperes by the power factor. See Art. **93.**

(*b*) A recording wattmeter is an instrument for recording the total amount of work done during a given time. The indicating wattmeter is a *power* indicator; or, in other words, it indicates the rate at which work is being done, whereas the recording wattmeter indicates the total amount of *work done* or *energy expended* in a given time.

(*c*) A recording wattmeter usually registers watt-hours or else gives a reading that, multiplied by a constant, gives the watt-hours expended.

(17) Alternating-current dynamos can be readily built to generate high pressures, because there is no commutator to give trouble. Also, alternating current can be easily transformed from one pressure to another, so that the current can be transmitted at high pressure and then lowered for use in

connection with lighting, the operation of motors, or any other purpose where high pressures would be objectionable. See Arts. **60** and **61.**

(18) From formula **20,** we have

$$\text{Watts} = \frac{R \times K \times 3,600}{T}.$$

In this case, $T = 80$ seconds, $R = 15$, $K = 2$.

Hence, $\text{watts} = \frac{15 \times 2 \times 3,600}{80} = 1,350$. Ans.

(19) (*a*) A mil is the thousandth part of an inch, i. e., 1 mil = .001 inch.

(*b*) A circular mil is a unit of area used for comparing and expressing the area of cross-section of wires. It is the area bounded by a circle the diameter of which is 1 mil or one-thousandth of an inch, and it is therefore equal to .0000007854 square inch. See Arts. **21, 22,** and **23.**

(20) This problem can be solved by using formula **19,** 25 horsepower = 25 × 746 = 18,650 watts. Hence, we have $18,650 = 1.732 \times 500 \times C \times .80$.

Hence,

$$C = \frac{18,650}{1.732 \times 500 \times .80} = 26.9 \text{ amperes. Ans.}$$

(21) (*a*) Because the single-phase system is not well adapted for the operation of alternating-current motors.

(*b*) For lighting work. See Arts. **62** and **63.**

(22) Yes; because when they are strung far apart there is a greater area between them for magnetism to thread through; hence, there will be a larger magnetic flux to cut the lines. See Art. **85.**

(23) No; the connections could not be made in this way, because the E. M. F.'s set up in the secondaries would be out of phase with each other and the transformers would send current around through each other's secondary coils.

(24) Because these systems allow the operation of alternating-current motors, which are self-starting and which can be constructed so as to start up under load if necessary.

(25) Because it is difficult to build direct-current dynamos and motors for the generation and utilization of current at high pressure, chiefly on account of troubles that arise in connection with the commutator. See Arts. **58** and **59.**

(26) (*a*) The transformers would be connected as shown in Fig. 31 (*d*).

(*b*) No; because if one transformer breaks down, the service is crippled, whereas with three transformers the remaining two will continue to supply current even if one transformer does break down. Of course, if the three transformers were connected **Y** instead of △, a breakdown would cripple the service, and this is one of the reasons why the △ connection is usually preferred.

(*c*) Three transformers of 15 kilowatts each would be sufficient. See Table VIII.

(27) See Art. **51.** Other conditions being equal, the size of the wire will be one-quarter as great, because the voltage has been doubled. The cross-section of No. 0000 is 211,600; hence, the cross-section of the required wire will be $\frac{211,600}{4} = 52,900$, or a No. 3 B. & S., very nearly.

(28) Because all the transformers may not regulate the same with changes in load, with the result that some of the transformers may become overloaded and blow their fuses, thus throwing an additional load upon the remaining transformers and blowing their fuses also. See Art. **75.**

(29) It allows double the voltage to be used and, hence, effects a saving in copper. See Art. **52.**

(30) (*a*) Double- or triple-braid weather-proof wire for the smaller sizes and weather-proof covered cable for the larger sizes.

(*b*) Lead-covered wire or cable insulated with paper or rubber. See Art. **19.**

(31) (*a*) Make a sketch similar to Fig. 28.

(*b*) Connect a pair of lamps in series across the outside lines. They should burn up to full brightness. See Art. **78.**

(32) (*a*) Make a sketch similar to Fig. 22, Art. **74.**

(*b*) Care must be taken to see that terminals of the same polarity are connected together. Similar terminals of the primary should be connected to the same mains, and terminals of the secondary having like polarity should be connected together, or a short circuit will result. See Art. **74.**

# ELECTRIC TRANSMISSION.

## (PART 2.)

---

(1) (*a*) About 1,000 circular mils per ampere.

(*b*) About 1,500 circular mils per ampere. See Art. **95.**

(2) (*a*) 22 inches in circumference or 7 inches in diameter.

(*b*) For ordinary lines, 40 poles to the mile should be sufficient; for heavy lines, 52 poles per mile should be used. See Arts. **3** and **5.**

(3) Porcelain insulators are not as likely to crack as glass when subjected to mechanical shocks. They maintain a higher insulation during rain storms, but their insulation is not as high as that of glass during dry weather. Also, porcelain insulators are more likely to have cocoons and cobwebs formed inside of them on account of the interior being dark. See Art. **8.**

(4) A deep-groove double-petticoat glass insulator similar to that shown in Fig. 4, Art. **9.**

(5) The conductors are placed in iron pipes that are filled with insulating compound. The tubes are buried directly in the ground and are not placed in ducts of any kind. The conductors are, therefore, not removable as in conduit systems. The lengths of tube are joined together by means of coupling boxes, which are filled with insulating compound after the conductors have been joined by means of flexible copper connections. See Art. **29.**

(6) So as to prevent the accumulation of gas that is likely to lead to an explosion. See Art. **21.**

(7) The two machines must be brought to the same voltage, and they must also be brought into synchronism; that is, they must be running at the same frequency and must also be in phase. Equality of frequency is the most important requirement.

(8) From formula **1,** we have

$$R = \frac{(V - V_1) r}{V_1}.$$

In this case, $V = 120$, $V_1 = 5$, and $r = 17{,}000$;

hence, $R = \frac{(120 - 5)\ 17{,}000}{5} = 391{,}000$ ohms. Ans.

(9) The length of the loop formed by joining the far end will be 24,000 feet; hence,

$$R = 24 \times .123 = 2.952 \text{ ohms},$$

and $x = \frac{1{,}000 \times 2.952 - 10 \times 162}{1{,}000 + 10} = 1.319.$

Hence, the distance of the fault from the testing station must be $\frac{1.319}{.123} \times 1{,}000 = 10{,}724$ ft. Ans.

(10) Either by means of synchronizing lamps or a synchronizing voltmeter. Synchronizing lamps constitute the simplest method and the one most commonly used. The connections of these lamps may be made so that when the machines are in phase the lamps burn up to full brightness, or the connections may be such that the lamps indicate synchronism when they are dark. The connections for the lamps are described in Art. **91.**

(11) See Art. **42;** also Figs. 39 and 40.

(12) (*a*) They should be placed on the line as well as in the station, because it is better to allow the discharge to pass off before reaching the station than to depend on the station arresters alone.

(*b*) No; it merely diverts the discharge by providing a path for it to pass off to the ground. See Arts. **44** and **45.**

(13) Because if a discharge comes in over both lines at once, a short circuit takes place between the gaps of the arrester, and a heavy rush of current would follow if the arc were not immediately extinguished.

(14) Alternators cannot be run in series unless they are rigidly connected together on the same shaft. If the machines were driven separately, their operation would be unstable. See Art. **76.**

(15) (*a*) Yes.

(*b*) Yes; it should connect the two points at which the brushes connect to the series coils. See Art. **85.**

(16) (*a*) No; not unless the field rheostats of the machines were continually regulated, and this would be hardly practicable if the load were a fluctuating one.

(*b*) Either provide the shunt machine with a series winding and run both as compound-wound machines or else cut out the series coils on the compound-wound machine and run both as shunt machines. The first method would probably be the better, because the compound-wound machines would maintain better voltage regulation. See Art. **88.**

(17) Because the discharge is oscillatory, and, on account of the high frequency at which it alternates, a high counter E. M. F. is set up in the inductive path.

(18) To interpose an inductive path between the line and the dynamo, and thus force the discharge to leap across the air gap of the lightning arrester. The kicking coil must always be connected between the device to be protected and the lightning arrester. See Art. **46.**

(19) No; because as soon as the machines are put in multiple, their series shunts are also in multiple, and any change in either shunt affects both machines. The adjustment should be made by inserting a small amount of resistance in series with the series field coil of the machine

showing the smaller drop through its series field. See Art. **86.**

(20) The full-load current of the large machine multiplied by the resistance of its series coil and switchboard lead must be equal to the full-load current of the small machine multiplied by the resistance of its field coil and switchboard lead. In other words, the drop through the two parts *a b* and *c d*, Fig. 63, must be equal. See Art. **86.**

(21) Yes; because the voltage of a shunt machine drops slightly with increase in load, and this tends to equalize the load between the machines. See Art. **82.**

(22) (*a*) Because if the load on one of the machines decreases, its voltage falls still lower because its field excitation decreases. See Art. **78.**

(*b*) By adding an equalizing connection so as to connect the fields of the machines in parallel. This wire connects the two brushes to which the fields are attached.

(23) (*a*) From 2 to 2.5 volts.
(*b*) From 2.2 to 1.8 volts.
(*c*) 1.8 volts. See Arts. **60** and **68.**

(24) No; the charging current forms certain chemical compounds that, when the cell is discharged, change back to their original form and in doing so set up a current.

(25) (*a*) The capacity is usually given in ampere-hours, i. e., the product of the normal discharge rate by the number of hours that the battery can maintain the discharge.

(*b*) Yes; a high rate of discharge decreases the output, and if carried too far may result in buckled plates. See Art. **59.**

(26) (*a*) The true efficiency is the watt-hour efficiency, because this gives the ratio of the total energy delivered to the total energy supplied. It is obtained by dividing the number of watt-hours delivered when the battery is discharged by the number of watt-hours supplied when the battery is charged.

(*b*) The ampere-hour efficiency is the ratio of the number of ampere-hours delivered to the number of ampere-hours supplied.

(*c*) Because the voltage required for charging is considerably higher than the voltage obtained at discharge, and moreover the voltage of the cells falls off as they become discharged. See Art. **59.**

(27) (*a*) Lead peroxide.

(*b*) Spongy lead.

(*c*) Both change to lead sulphate. See Art. **56.**

(28) The plate at which the current flows in when the cell is charging and out when it is discharging. See Art. **55.**

(29) In the Planté plate the active material is formed on the lead plate itself either by chemical treatment or by repeated charging and discharging. In the Faure, or pasted, plate the active material is applied in the form of a paste and is held in grooves or openings provided for the purpose. See Arts. **57** and **58.**

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